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Network-Theoretic Creation of Financial Liquidity by Computing Supply-Demand Flows

Abstract

We build upon proven financial instruments (futures contracts and Liquidity Savings Mechanisms) to introduce algorithms that can construct new credit pipelines in rapidly changing pathways. They solve liquidity problems similar to how routing algorithms behind the Internet solve connectivity problems. Such a liquidity-Internet could allow solvent businesses and ideas with demand to get started and keep operating irrespective of legacy liquidity problems. The proposed model can also expand investment opportunities by removing information asymmetry. Because the computed supply-demand loops define an intelligent life-cycle for this new capital, it can be monetized non-inflationary and using any conventional currency.

Introduction

Only 0.5% of entrepreneurs in the US receive venture capital (Kaufman, 2019). Most small businesses seek loans under $100,000 while banks are increasingly avoiding requests below that level (Forbes, 2014). Ironically, the total money in economies keeps vastly expanding, yet failing to translate into healthy markets (Roubini, 2015) and business growth (Summers, 2016). These failures to source and move money productively can be explained as failures of liquidity (ECB, 2009) and are becoming particularly acute under the current economic challenges.

As far as we know, the proposed I-Owe-the-Network (ION) contracts are the first financial instruments for economic growth not limited by the past, i.e. by how existing money is distributed. At a first glance, IONs are similar to futures contracts, forward contracts, or IOUs. However, to create any of these at least one party must have money to commit. Therefore, they are directly affected by systemic liquidity problems.

IONs overcome this by performing accounting similar to Liquidity-Saving Mechanisms (LSMs) which banks have used for decades to solve inter-bank payment gaps without having to get additional loans themselves. However, LSMs operate isolated and in bank backends. IONs, on the other hand, expose this ability in a networked form by algorithms that have been proven over decades in Internet routing protocols and more recently in social networks.

Until the past decade, we could only have had 'transfer-and-keep' payment instruments which one must keep to keep the payment. It is only the past decade that has made the 'flow-through' payment nature of IONs possible. In addition, economic markets have long been described as computing devices of the pre-electronic age (Lange, 1967). However, it is the advances of the past decade in network theory and technology that have made it possible to use the computing potential inherent in markets. In a network-theoretic model, economic participants are modelled as network nodes and their supply-demand relationships are modelled as links. An economic transaction can be modelled as an information flow between a supply node on one end and a demand node on the other, but also including any number of intermediary network nodes in between. Such a multi-hop flow has a greater information capacity compared to today's single-hop transactions, that are a direct line between only two nodes. At the same time, multi-hop transactions could execute instantly and as seamless as single-hop.

A key quality of the proposed model is that it does not replace or subvert conventional money, but only upgrades its monetary policy options and expands its capacity for economic information. IONs can be a new tool for a key problem of the investment industry, information asymmetry, which distorts the ability to make loans. Instead of handing out their capital in bulk to a business, investors can stream their capital through ION flows by market-making for them. This gives investors visibility of the same information businesses have. Credit-clearing groups and community currencies are also independent from mainstream liquidity, but unlike IONs they require their own local currencies and payees need to trust their private payment unit. For governments, IONs offer a novel way to increase money supply. The options today involve increasing debt and/or printing money and risking inflation. IONs avoid both because they are created out of specific productive activity and deleted when its supply-demand loop closes.

This paper focuses on a more straightforward application to conventional business activities, i.e.

where products or services have explicit demands for purchase. However, it also introduces applications to activities that fall out of today's markets, such as volunteering, non-profit, or philanthropy. Such activities often have a clear economic value, like in the case of open-source projects (e.g. Linux) that is widely used for commercial reasons. IONs can achieve a form of social value underwriting that blurs the lines between non-profit vs profit and work vs volunteering.

Related Works

Easley and Kleinberg (2010) review the potential of network science for economic modelling and highlight application domains such as auctions and matching markets. These applications focus on optimal end-state of supply-demand networks and not on the flow of a single transaction across network nodes. They see transactions as primarily single-hop. Matching markets which model intermediaries like clearinghouses begin to consider multi-hop aspects, usually as a composition over two hops with a single intermediary. However, there is still no concept of a single transaction leaving value across multiple network nodes during an elementary completion.

More relatedly, certain matching markets begin to account for cycles, i.e. considering what happens when a sequence of supply-demand network edges close into a loop. For example, consider a sequence where the 1st node's demand connects to the 2nd node's supply and so on for any length, until the penultimate node's demand connects to the last node's supply. When the last node's demand connects back to the 1st node's supply, this sequence wraps into a loop. Shapley and Scarf (1974) introduced the Top Trading Cycle (TTC) algorithm, developed by David Gale, which seeks such cycles iteratively because it allows for the simultaneous execution of all swap trades in a loop, while running an economy that is core-stable and guaranteeing a competitive equilibrium. Abdulkadiroğlu and Sönmez (1999, 2003) extended the TTC algorithm to support nodes with yet unmatched supply or demand while retaining the desirable algorithm properties. In an application for kidney exchanges, Roth, Sönmez and Ünver (2004) further extend the TTC algorithm to support incomplete loops by buffering the value moving over the loop into a waiting list.

Unlike the related work above, the proposed model is not based on indivisible swap or barter exchanges. Instead, IONs underwrite the traded value in a representation that is perfectly divisible and can split and flow in any way over the network, allowing a single ‘unit’ of the traded value to be traded over many-to-many connections between the supply and demand multi-node partitions. Also, incomplete loops are supported inherently without needing buffers such as waiting lists.

The idea of a decentralized monetary policy with multiple issuers of payment media has considerable theoretical and practical precedents. Selgin and White (1994) provide a comprehensive review that identifies three strands of such precedents: (i) where the various issues are redeemable in a common base money; (ii) where there are multiple brands of non-commodity base monies; (iii) and where there is no base money at all. IONs relate to the second and third strand. On the second, Selgin and White point out that ‘one can imagine, as Benjamin Klein (1974) and F. A. Hayek (1978) have, laissez faire competition among multiple brands of “private fiat money”’. However, issuers would have to provide an ‘enforceable precommitment with an infinite horizon,’ assumed impossible, to avoid issues with hyperinflation and optimal quantity of money. IONs can overcome this hitherto impossibility because their life-cycle avoids having to deal with infinite horizons (i.e. untethered circulation) while their tethered nature serves as a clear precommitment.

The third strand is described by Selgin and White as having the medium-of-exchange be based on claims and the unit-of-account be a deliberately separate numeraire. The goal is to tackle a problem with conventional base standards (commodity or fiat) where ‘a change in the purchasing power of the monetary unit … can only be achieved through the protracted process of adjusting the nominal prices of goods and services generally’. Related ideas are criticized on the feasibility of decoupling unit-of-account prices. The reviewed proposals consider monetary decentralization that goes down only to the level of banks. Their new unit-of-account numeraire is a ‘broad bundle comprising specific amounts of a variety of standardized commodities’, thus not as decoupled. On the other hand, IONs can decentralize money down to individual economic activities, resulting into a novel unit-of-account function, a numeraire expressing exchange rates between IONs, that is completely neutral to the medium-of-exchange function.

Fare and Ahmed (2018) also discuss monetary decentralization, from a more current perspective and focusing on what they call complementary currency systems (CCSs) such as LETS (Local Exchange Trading Systems), WIR in Switzerland, or the local currencies of barter clubs in Argentina. They point to 3,500 to 4,500 CCSs across 50 countries, with those in Argentina involving as much as 2.5 million people. The decentralization fidelity in CCSs goes further below banks, towards less formal actors of civil society issuing the currency. However, within a single CCS the currency is still generic, which means existing CCSs cannot address the separation of medium-of-exchange and unit-of-account functions like IONs could.

The limitations of a generic currency are particularly acute in CCSs. The generic quality usually means that trust in the currency has to be anchored into a central authority, but CCSs by their nature struggle with organizing and sustaining a central authority. Another consequent problem is an imbalance that can form between those who want to spend the complementary currency and those who are willing to accept it. CSS participants can be hesitant on the accepting side, especially when they suspect the currency will remain long with them before they get a chance to spend it. Another reason for the imbalance may be that a CSS participant has nothing on offer that the CSS community needs in a particular moment.

IONs can avoid the above problems above because they are issued from a value origin point and can be spent only while creating an exact acceptance inflow at the same point. At the same time, anybody outside of that sub-economy can accept it as a payment instrument without having to trust it, because the ION delivers its value without stopping outside the sub-economy.

Implementing IONs

Currencies by themselves do not carry information about source economic activity or the monetary policy that created each unit of currency. This includes all national currencies and practically all existing crypto-currencies. IONs can be thought of as digital labels over currencies, tethering units to their source economic activity. In the case of crypts, it is straightforward to add the labels into their blockchains. More importantly perhaps, it is relatively simple to apply IONs to non-crypto currencies, especially to digital forms of conventional fiat currencies. Various central banks are publicly considering digital fiat money, such as Bank of England (Broadbent, 2016), Sweden's Riksbank (Riksbank Sveriges, 2018), Bank of Canada (Chiu et al. 2019). These central bank digital currencies (CBDCs) have no need of a blockchain since their serialized units are simply digital versions of paper money that are managed from a central database. The activity-share label can be an additional attribute in the schemas of those future databases.

It is also possible to contrive an implementation of IONs in an economy before it gets access to

CBDCs. Financial companies are increasingly exposing web interfaces to customer data through publicly accessible APIs (application programming interfaces) (Gozman et al. 2018; Zachariadis & Ozcan, 2017). Access to these interfaces is given not only to customers but third-parties as well. In the case of the European Union such access is now mandated by law (European Central Bank, 2018). Financial companies can implement the activity-share label by editing schemas of their existing databases. The label can then be passed between institutions or customer apps (e.g. bank or e-commerce apps), by adding it to the other attributes included in API transactions. The central bank could optionally be involved by adding the attribute to their pre-CBDC systems for sight deposits of commercial banks.

Technically, IONs can be run as a graph database (Robinson & Webber, 2015) which can execute the algorithms described below. Such a database can be owned and operated by any public or private entity. Multiple ECOGs can inter-connect in a manner similar to how the Internet is made up of many public and private TCP/IP networks (Stewart, 1999), by connecting at peering points over which routing protocols can exchange flow information.

Inside the Liquidity Network

Summary of the Algorithms

When a node C^{π} is engaged in creating some product or service π, new ION^{π} is issued in successive units into the ION network with C^{π} as the origin. All the other nodes in the ION network are split in two groups with regards to ION^{π}:

(1) $\mathbf{A}^{\pi}$ consists of all who acknowledge the value of ION^{π}. This could be nodes who have a demand for π and want ION^{π} because it is the optimal currency to pay C^{π} with. $\mathbf{A}^{\pi}$ could

also be nodes who accept ION^{π} as a form of payment without intending to buy π but because they want to support or invest in π or C^{π}, as discussed later.

(2) **NotA$^{\pi}$** consists of all who do not accept ION^{π} and may not even know of ION^{π}, π, or C^{π}.

The ION network instantly transfers ION^{π} across **NotA$^{\pi}$** nodes as it moves it from C^{π} to **A$^{\pi}$** nodes, while financially benefiting all the **NotA$^{\pi}$** nodes along the flow path. The benefits involve settling balances between **NotA$^{\pi}$** nodes that have nothing to do with π. Each unit of ION^{π} has a finite economic life-cycle:

(1) Each ION^{π} unit quantifies progress in the creation of π, in whatever way the ION^{π} stakeholders (C^{π} and **A$^{\pi}$**) define that process. The issuance by itself does not give ION^{π} any value. It gets value only when bids and asks begin matching between C^{π} and **A$^{\pi}$**.

(2) Each ION^{π} unit circulates throughout the economy representing its π value, but the association is only theoretical and for information purposes. Practically, it can be used as a store-of-value and medium-of-exchange involving any product or service.

(3) When a buyer pays for π using ION^{π}, those units of ION^{π} flow back to C^{π}. Since the demand they denominated no longer exists, they are annulled in the ION network.

In summary, the movements of ION^{π} generally happen as follows:

(1) ION^{π} is issued as originating from C^{π} who is creating a product or service π.

(2) ION^{π} enters circulation as C^{π} uses it for payments to **A$^{\pi}$** or **NotA$^{\pi}$** nodes.

(3) ION^{π} flows towards **A$^{\pi}$** nodes while benefiting any number of **NotA$^{\pi}$** nodes in its path.

(4) When ION^{π} reaches **A$^{\pi}$**, it can stay there as store-of-value for any length of time.

(5) **A$^{\pi}$** nodes can use their stored ION^{π} to pay **A$^{\pi}$** or **NotA$^{\pi}$** nodes for anything other than π.

(6) Payments always move ION^{π} from one $\mathbf{A}^{\pi}$ node to another $\mathbf{A}^{\pi}$ node, while servicing any number of $\mathbf{NotA}^{\pi}$ balances in the path.

(7) When an $\mathbf{A}^{\pi}$ node finally goes to buy π, a required amount of ION^{π} returns to C^{π}.

(8) Because each ION^{π} underwrites a specific amount of supply-demand matching, after a purchase the returned ION^{π} is annulled.

A number like 2 ION^{π} expresses only a contract token count by itself, i.e. only a specific amount of π. The transactional value of ION^{π} is expressed in terms of any currencies 1 ION^{π} = \$3.4. This rate can be fixed as in most consumer transactions today, or the ION network can also support bids and asks similar to commodity futures markets. Both C^{π} and $\mathbf{A}^{\pi}$ can state any initial bid or ask for ION^{π}, expressed in terms of any other currency. The exchange rates are likely to converge, since any gaps between rates are likely to be detected and exploited by market-makers and other traders, especially in an environment of increasing trading automation.

Market-Makers for IONs

C^{π} may not have sufficient network connectivity to $\mathbf{A}^{\pi}$ nodes, preventing it from spending its ION^{π} directly over network flows. One solution can be inspired by stock markets which depend on market-makers for liquidity. An ION market-makers can insert itself transparently between the payer and payee, instantly bridging their flow gaps without complicating their experience. Figure 2 illustrates an ION market-maker buying ION^{π} from C^{π} at time t_1, when C^{π} uses it to pay a $\mathbf{NotA}^{\pi}$ node which does accept ION^{π}. Figure 2 also shows the market-maker later at time t_2 selling the ION^{π} to an $\mathbf{A}^{\pi}$ node which needs it to pay C^{π} for π. Market-makers can be motivated by profits from selling ION^{π} over the buying price, or non-profit market-makers may simply want to support C^{π} until the ION network becomes sufficiently connected.

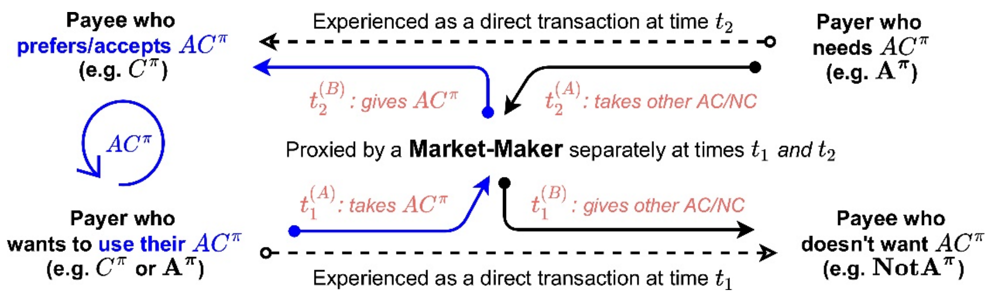

Figure 2. ION market-maker buying and selling IONs to bridge flow gaps.

ION-Enabled Applications

Producers, consumers, market-makers or other third parties need some type of ION-enabled applications (IEAs) to participate in a ION network. IEAs could be existing e-wallets or e-commerce apps that are modified to carry the ION label and to interface with ION network graph databases. Theoretically, users could use multiple IEAs for the same ION network, or a single IEA for multiple ION network. The primary function of IEAs is to be the source of newly issued IONs. Even if the issuance is centrally controlled by a government, new ION units enter circulation from IEAs of activity operators. Another function of the IEAs is to hold information about the offers and demands of a user. This paper focuses on offers made by creators of products and services, like C^{π}, where the IONs originate. This does not interfere with IEAs also handling second-hand offers of the same products and services, or payments with an ION outside their origination point. However, these functions would not be any different from how e-commerce apps already do this with NC.

Minting Algorithmic Contracts

The ION contract defines what constitutes a unit of product or service and when a new ION^{π} unit is issued. For example: (i) for a factory, each product can be the unit and a new ION unit can be issued as soon as a product leaves the production line; (ii) for contracted work each working hour can demark the ION units; (iii) for a farmer, each land unit or weight of produce could be a unit, generating new ION units at different stages of the growing season.

The validation of ION contract compliance can be done just like in commodity futures markets today, using margins and other guarantees. So the worst case is equivalent to today. However, ION compliance can be easier because their digital and computational validation is an increasingly easier task in a world undergoing Industry4.0 and digital transformations. Many products can now continuously report into the Internet of Things from the moment they leave the factory line. Analysing streaming video of a farm or a factory by machine learning algorithms is already a commodity service. Because a ION contract is a programmable contact, it could theoretically implement any conceivable validation logic.

Activity operators like C^{π} could initiate and run any number of ION contracts from their IEAs. ION contracts could be from external sources or self-defined. An externally-sourced ION contract can be predefined and published by someone who manages an existing demand. C^{π} would copy such a ION contract into its IEA and execute it to begin issuing ION^{π} based on its progress in π creation. A user could also self-define a ION contract on their own, describing a new planned activity, and then try to organize its $\mathbf{A}^{\pi}$. No external verification is needed for ION contract creations because the mere generation of IONs does not give them any value. ION contracts are administered mutually by C^{π} and $\mathbf{A}^{\pi}$ nodes.

The Concept of Instant Network Flows

Figure 3 illustrates a primitive instant network flow (INF) of a single hop between two directly connected nodes. Node C^{π} is manufacturing a product π, issuing ION^{π} during the production and posting π on an offer payable in ION^{π}. Let node A_1^{π} be a node who has a demand for π. We will express this circular relationship of offers and demands as ${}_{\pi}\circlearrowleft C^{\pi} \hookleftarrow_{\beta} A_1^{\pi} \circlearrowright_{\pi}$. The only point of this naive example with no **NotA**$^{\pi}$ nodes is that A_1^{π} can accept ION^{π} as payment currency (INF 2 in Figure 3) because A_1^{π} later needs ION^{π} to pay C^{π} for π (INF 3 in Figure 3).

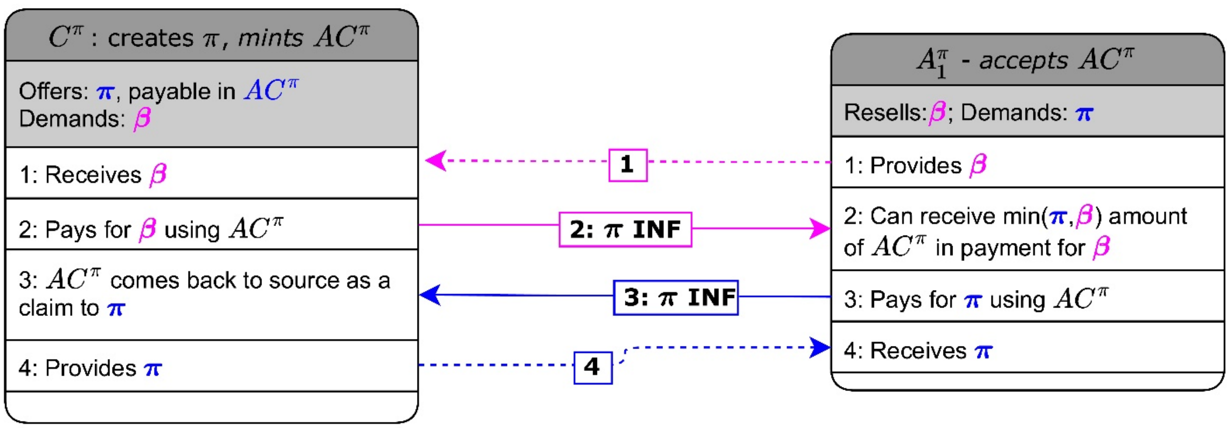

Figure 3. A primitive single-hop example between directly connected supply & demand.

Figure 4 extends the primitive example by inserting two **NotA**$^{\pi}$ nodes between C^{π} and A_1^{π} with the following relationship: ${}_{\pi}\circlearrowleft C^{\pi} \hookleftarrow_{\gamma} N \hookleftarrow_{\delta} M \hookleftarrow_{\beta} A_1^{\pi} \circlearrowright_{\pi}$, i.e. N provides products/service γ to C^{π}, M provides δ to N and A_1^{π} provides β to M. The transactions 1.A, 1.B, 1.C could have happened independently at any time. N and M may not even know about π or ION^{π}. The demand for π is again at A_1^{π}, however it is now two hops away from C^{π}. The point here is that N can accept ION^{π} as payment from C^{π}, because N has a balance with M, M has a balance with A_1^{π} and A_1^{π} needs to pay C^{π} with ION^{π} for π. We will assume for the moment that payment is simultaneously due at each hop.

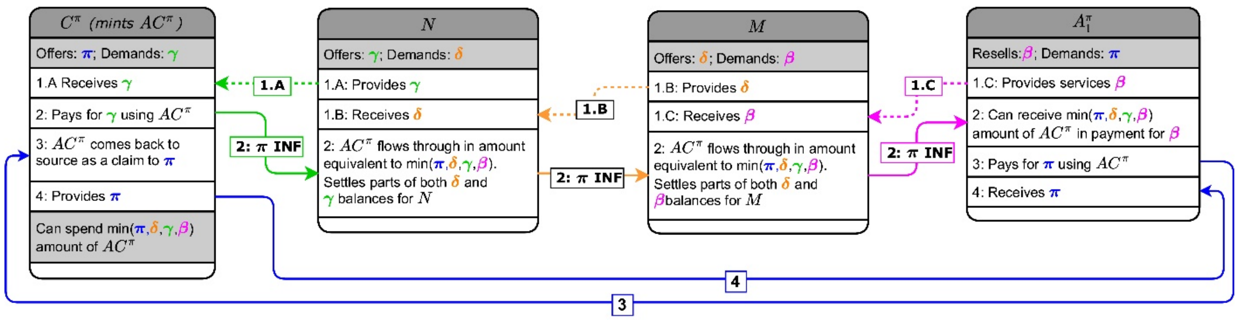

Figure 4. Depth expansion example with two intermediary nodes added.

In this extended scenario, when C^π pays with ION^π on one end of the INF, the ION network instantaneously settles all the intermediary balances based on ION network exchange rates, and ION^π simply shows up on the other end in A_1^π's IEA. Therefore, the ION^π flow is only theoretical. N and M never handle ION^π in practical terms.

Let $B^{C\pi\text{-}N}$, $B^{N\text{-}M}$, $B^{M\text{-}A}$ be the balances of the unsettled balances at hops C^π-N, N-M and M-A_1^π respectively, expressed in any currency. These balances are a result from some previous exchange of products or services, in this case γ, δ and β respectively. The existence of balances in a connected sequence results in an open INF $f = C^\pi \twoheadrightarrow N \twoheadrightarrow M \twoheadrightarrow A_1^\pi$ that can be used by any ION or a combination of multiple IONs. The maximum value that INF f can theoretically transfer is $min(B^{C\pi\text{-}N}, B^{N\text{-}M}, B^{M\text{-}A})$, regardless of which IONs are using that capacity.

When ION^π uses the INF, f moves some amount $x^{ION\pi}$ of ION^π through the following 3 steps that are executed simultaneously by the ION network:

(1) Decrease all balances ($B^{C\pi\text{-}N}$, $B^{N\text{-}M}$, $B^{M\text{-}A}$) on the path by an amount equivalent to $x^{ION\pi}$

(2) Deduct $x^{ION\pi}$ from C^π's IEA

(3) Add $x^{ION\pi}$ to A_1^π's IEA

The $x^{ION\pi}$ amount is not only limited by the capacity of f but also by the amount of ION^{π} that A_1^{π} is willing to accept. If we label this acceptance limit as $y_A^{ION\pi}$, then the maximum $x^{ION\pi}$ that $f(ION^{\pi})$ can achieve in practice is $min(B^{C\pi\text{-}N},B^{N\text{-}M},B^{M\text{-}A},y_A^{ION\pi})$, assuming that only ION^{π} is using flow f. Figure 4 simplifies the case by having $y_A^{ION\pi}$ be $B^{A\text{-}C\pi}$ from the π transacted between C^{π} and A_1^{π}, however we will see later that this is only one possible addend to $y_A^{ION\pi}$.

In the example above, the INF f was expanded linearly in depth, adding intermediary levels between a single supply node and a single demand node. INFs can also expand in breadth, as shown in Figure 5, where f branches out at various level and becomes more tree-like instead of linear. Every leaf-node of this flow tree becomes an additional $\mathbf{A}^{\pi}$ node, increasing the amount of ION^{π} accepted across the ION network, and thus the amount of ION^{π} that can be spent by C^{π}.

In Figure 5, $\mathbf{A}^{\pi} = \{A_1^{\pi}, A_2^{\pi}, A_3^{\pi}\}$ is a set of accepting nodes for ION^{π}, and each of them accepts respectively $y_{A1}^{ION\pi}$, $y_{A2}^{ION\pi}$, $y_{A3}^{ION\pi}$ amounts of ION^{π}. C^{π} can now spend ION^{π} through multiple INF branches. When C^{π} pays M over flow 2.A it can spend $min(B^{C\pi\text{-}M},B^{M\text{-}A3}, y_{A3}^{ION\pi})$, but when C^{π} pays N over flow 2.B it can spend $min(B^{C\pi\text{-}N}, (min(B^{N\text{-}A2}, y_{A2}^{ION\pi}) + min(B^{N\text{-}A3}, y_{A3}^{ION\pi})))$. Figure 5 shows INF 2.B splitting after N into 2.B-1 and 2.B-2. The complexity of flows always remains hidden from all nodes, including C^{π}.

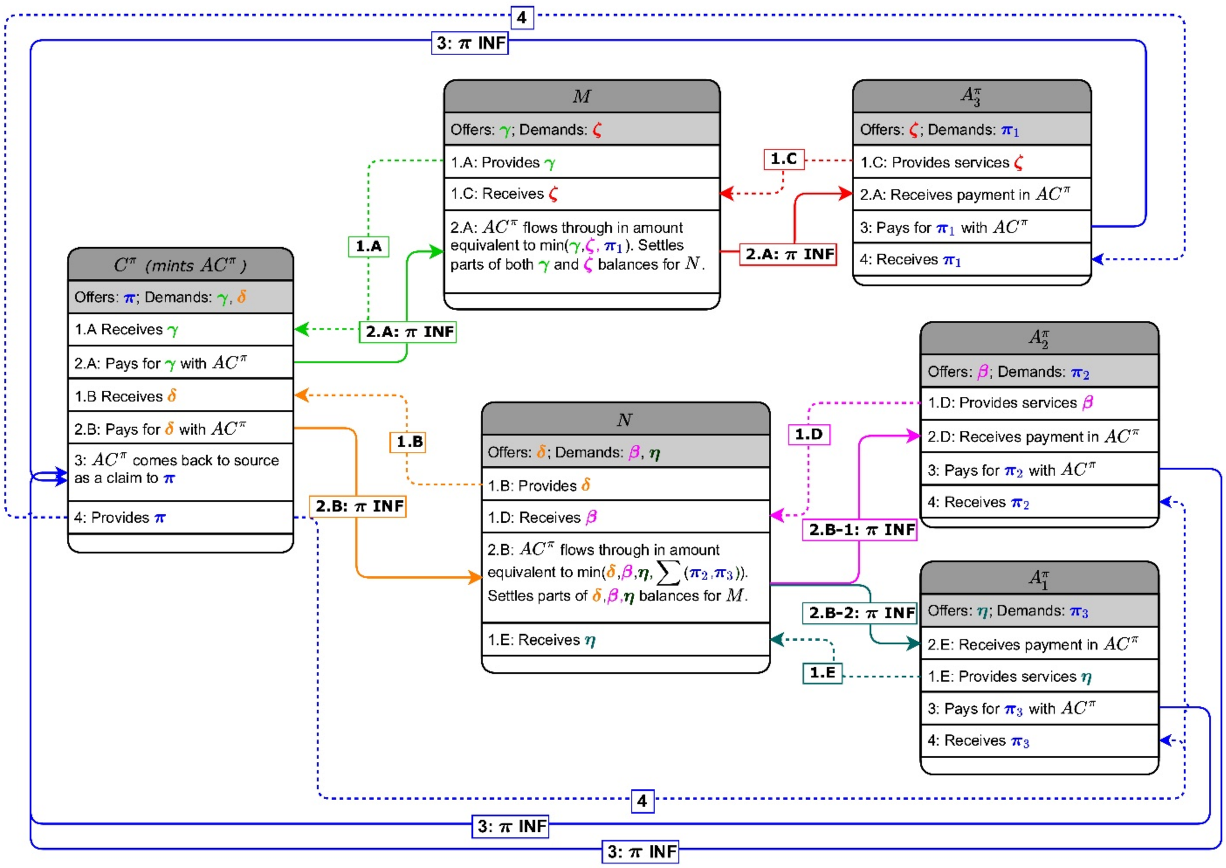

Figure 5. Breadth expansion example with the flow splitting on two levels.

Requirements to Form an INF

In the discussion above, ION^π was able to flow because we assumed that the $\mathbf{A}^\pi$ set already existed, i.e. the ION network knew of nodes wanting π or willing to accept ION^π. We also assumed that there were unsettled balances at consecutive hops between C^π and $\mathbf{A}^\pi$, i.e. the ION network had enough *Bs* lined up. Next we look at how these requirements become satisfied and the possible user experiences (UXs) in IEAs.

1st Requirement: Non-Empty A^π Set

UX2 in Figure 6 shows C^π posting an offer for 100 units of π with an elementary price of $1ION^\pi$ per unit of π. The π ION contract may then allow C^π to spend $100ION^\pi$. The first requirement for an INF is a non-empty $\mathbf{A}^{\pi}$, a set of nodes where flows must terminate. A node joins the $\mathbf{A}^{\pi}$ set when it signals to the ION network that it accepts ION^{π} as payable currency for any of its offers. This can happen automatically when a node posts a demand for π, such as A_3^{π} (UX4) in Figure 6. The posted demand implicitly means that A_3^{π} will want enough ION^{π} to pay for the desired π, in this example $5ION^{\pi}$ for the desired 5π. The ION network thus sets $y_{A3}^{ION\pi} = B^{A3\text{-}C\pi} = 5ION^{\pi}$ and the IEA of A_3^{π} begins to accept up to $5ION^{\pi}$ when A_3^{π} takes any payments. A_3^{π} also states its subjective bid rate for ION^{π} in any ION or currency of its choice, in this case as $1ION^{\pi}$=\$2.47. If all requirement for an INF were met, this bid would show up in UX1 for C^{π} as an option. However, UX1 does not show it because there is not enough balance capacity between C^{π} and A_3^{π} yet.

Individual bids are shown in UX1 for illustration only. In actual experience, C^{π} does not have to see flows at this granularity. C^{π}'s IEA can automatically use up bids in order of preference, whether simply by sorting them by bid amount or also considering other constraints given by a user. The constraints can be only thresholds or more complicated rule-based logic. If A_3^{π}'s bid rate is too low compared to other bid rates, its bid is less likely to be used and A_3^{π} may not get enough ION^{π}. A_3^{π} can always choose to use market-makers to execute the purchase right away without having to deal with IONs.

A node could also join the $\mathbf{A}^{\pi}$ set without an intent to purchase any π. There may be scenarios, discussed later, where A_1^{π} only wants to support ION^{π} or C^{π}. UX3 in Figure 6 shows node A_1^{π} signalling that it will accept up to 70 units of ION^{π} at a rate of 1 ION^{π} = \$2.33. A_1^{π} also states the maximum amount of ION^{π} it is willing to accept, $y_{A1}^{ION\pi}$=70 in the example.

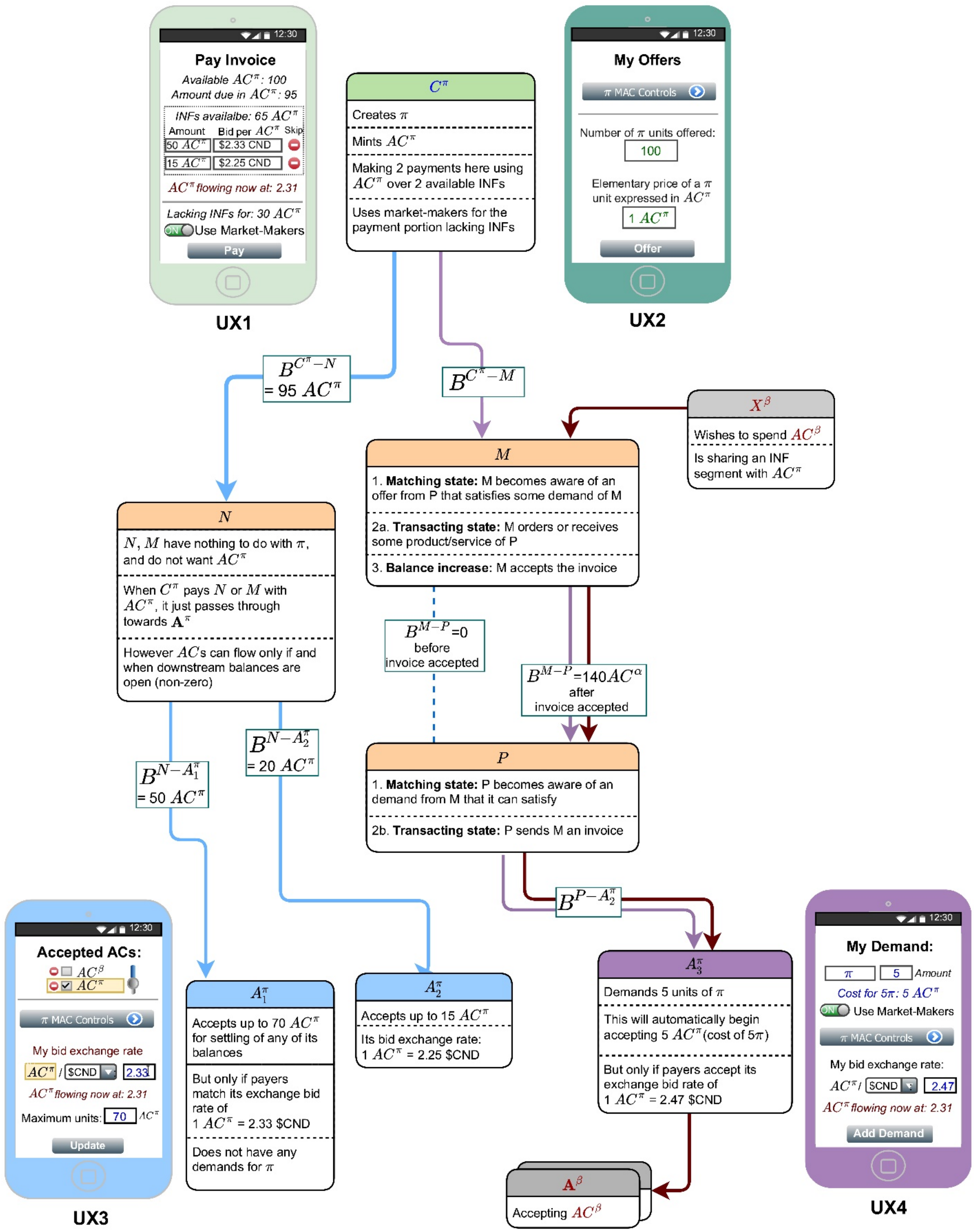

Figure 6. User experience (UX) examples during ION network transactions.

The commitment from an $\mathbf{A}^{\pi}$ node to accept ION^{π} is not binding and can be retracted at any time. This would stop future ION^{π} coming in, but any ION^{π} that has already reached its IEA would stay there. Also, a demand node like A_3^{π} does not have to execute the π purchase immediately after receiving ION^{π} or even at all. It can keep the ION^{π} as a store-of-value or exchange it through market-makers for another ION or NC.

2^nd^ Requirement: Balance Capacity Along Sequential Hops

The second requirement for a path from C^{π} to any $\mathbf{A}^{\pi}$ node to become an INF is for each hop along that path to have an unsettled balance $B^{X\text{-}Y}$. Unlike the first requirement where the ***A*** nodes are specific to an ION (e.g. $\mathbf{A}^{\pi}$ nodes are for ION^{π}), hop balances are independent of the IONs that use them. A balance is like a diameter of a pipe carrying a liquid flow and independent of the composition of the liquid. Each balance $B^{X\text{-}Y}$ can be an accumulation from multiple previous transactions involving any products or services which may be completely unrelated to ION^{π}, $\mathbf{A}^{\pi}$ nodes, or C^{π}.

Each increase to a hop balance goes through the following state changes:

(1) *Matching state*: reached when the ION network sees a potential match between an offer from one node and a demand from another node. If no previous transactions have occurred yet between the two nodes, the balance is still zero and the nodes may not even be aware of each other. Otherwise, the matching state may begin with a non-zero balance.

(2) *Transacting state*: reached when the two nodes engage on the offer-demand match and some transaction or agreement happens between them, such as sending a proposed invoice or negotiation of terms.

(3) *Balance increase*: happens when both nodes agree on the match execution. If this is the first transaction that changes a hop balance from zero to non-zero, the hop is said to have changed from *closed* to *open*.

The currency terms in an invoice would be similar to existing practices in international trade: (i) both parties agree on the currency denominating the value exchanged, which could be different from their native currencies; (ii) if they are not comfortable with the currency fluctuating during the period payment is due, they can agree on a fixed rate or a rate schedule.

Besides balance increases, a balance can be decreased whenever it is used by any ION that flows through that hop. The value of the passing ION is subtracted from the balance, decreasing the amount payable for the upstream node and decreasing the account receivable for the downstream node.

In Figure 6 for example, the balance $B^{M\text{-}P}$ starts off as zero, i.e. the *M-P* hop is in a *closed state*. After node *P* sends an invoice to *M* and the invoice is accepted, a payment becomes due from *M* to *P*. This increases $B^{M\text{-}P}$ from *0* to *140* ION^{α} and makes the hop *M-P open*. Now any INF reaching *M* can use this hop to continue to *P* and beyond it. A key thing to note is that $B^{M\text{-}P}$ is between two **NotA**$^{\pi}$ nodes and has nothing to do with $\mathbf{A}^{\pi}$ nodes or C^{π}. $B^{M\text{-}P}$ is in terms of ION^{α} which is unrelated to ION^{π}. Still, $B^{M\text{-}P}$ needs to become non-zero (i.e. for hop *M-P* to *open*) in order for ION^{π} to flow from C^{π} to $A_3{}^{\pi}$. And not only the *M-P* hop, but hops C^{π}-M and P-$A_3{}^{\pi}$ also need to be open at the same time. Each hop goes independently through the hop state changes described above and on its own time.

Likelihood of INF Formation

The likelihood of having a sequence of concurrently open hops between two nodes (i.e. a spendable INF) is related to the average degree of separation between two nodes in a supply-demand network. Many networks involving social relationships fall under the category of 'small-world' networks (Watts & Strogatz, 1998), where most nodes are not directly connected but connect to a much smaller number of hubs. The degree of separation in such networks, i.e. the sequence of hops between two nodes, is a surprisingly small number on average, e.g. 3.57 for Facebook in 2016 (Bhagat et al. 2016) and 3.4 for Twitter in 2011 (Bakhshandeh et al. 2011). The smaller this average degree of separation, the higher the likelihood that all hops along the sequence can have a certain property concurrently, like have an open balance concurrently in the case of an ION network.

Even though results in small-world networks can seem encouraging, the degree of separation in an ION network is an open empirical question. One hopeful consideration is that frequent conglomeration in market economies would contribute towards shorter degrees of separation and therefore higher likelihoods of INFs. Another helpful consideration is the possibility of network-graph augmentation once an ION network gets started. If market-makers can bootstrap an ION network by hiding the INF gaps at first, incentives can develop for users to bridge the gaps themselves as described later.

Spending Over INFs

An INF can be used to spend any IONs as long as somewhere downstream it can reach accepting nodes for those IONs. In Figure 6 for example, when the hop *M-P* is closed due to a zero balance, the only spendable INFs are $C^{\pi} \twoheadrightarrow N \twoheadrightarrow \{A_1{}^{\pi}, A_2{}^{\pi}\}$ and the direct $P \twoheadrightarrow A_3{}^{\pi}$ hop. As soon as hop *M-P* turns open, INF $C^{\pi} \twoheadrightarrow M \twoheadrightarrow P \twoheadrightarrow A_3{}^{\pi}$ and $X^{\beta} \twoheadrightarrow M \twoheadrightarrow P \twoheadrightarrow A_3{}^{\pi} \twoheadrightarrow A^{\beta}$ also become spendable. Note that the INF segment $M{\twoheadrightarrow}P{\twoheadrightarrow}A_3^{\pi}$ is shared by both C^{π} & X^{β} and both ION^{π} & ION^{β} are being spent over it. Therefore, whatever capacity one ION uses up along the shared INF (i.e. out of B^{M-P} and B^{P-A3}), is removed from the available capacity for other IONs. Another key point is that origin nodes like C^{π} are not the only ones that can spend an ION down an INF. For example, X^{β} might have received ION^{β} from someone else and may not be related to the β creation activity (i.e. to C^{β}).

UX1 in Figure 6 shows the experience for C^{π} when it goes to make a payment due to N. We see that the balance owed to N is 95 as expressed in ION^{π}. As a reminder, N may not accept, care, or even know about ION^{π}. $B^{C\pi-N}$ may have been set in some other IONs or currencies and 95 ION^{π} is simply the equivalent. C^{π} has 100 ION^{π} available, however it does not have access to enough open INFs for the full 95 ION^{π}. We see that C^{π} can spend only 65 ION^{π} over INFs towards N because the capacity of the $C^{\pi}{\twoheadrightarrow}N{\twoheadrightarrow}\{A_1^{\pi}, A_2^{\pi}\}$ is $min(95,(min(50,70) + min(20,15))=65$.

For any portion of the invoice lacking INFs, such as 30 ION^{π} in UX1, C^{π} can use market-makers who will transparently convert the 30 ION^{π} in the backend into whatever ION or currency is accepted by N. In the end, C^{π} still gets to pay the full invoice in ION^{π}.

When C^{π} makes such a 95 ION^{π} payment, the following things happen instantaneously:

(1) 95 ION^{π} are deducted from the IEA of C^{π}, leaving it with 5 ION^{π}

(2) The $B^{C\pi-N}$ balance is fully cleared and C^{π} doesn't owe anything more to N

(3) The B^{N-A2} balance is partially cleared from 20 ION^{π} to 5, since A_2^{π} was accepting only 15

(4) 15 ION^{π} end up in the IEA of A_2^{π}

(5) The B^{N-A2} balance is fully cleared

(6) 50 ION^{π} end up in the IEA of A_1^{π} (From here on, A_1^{π} accepts only 20 ION^{π})

(7) 30 ION^{π} end up with the market-maker

(8) The used-up flows disappear from the user interface of C^{π} (UX1 in Figure 6)

(9) The 'flowing now at' average, seen in UX1, UX3 and UX4 is updated

If ION^{π} is not used for a π purchase right after it flows into A_1^{π} and A_2^{π}, that ION^{π} could spend time circulating within the $\mathbf{A}^{\pi}$ sub-economy as a medium-of-exchange whenever one node in $\mathbf{A}^{\pi}$ pays another $\mathbf{A}^{\pi}$ node that is still accepting ION^{π}. For example, if A_2^{π} had to pay A_1^{π} for anything, it could use its 15 ION^{π} because A_1^{π} is still accepting 20 ION^{π}. This payment flow could pass through a different set of $\mathbf{NotA}^{\pi}$ nodes.

ION Annulment at Claim Execution

When a purchase of π happens eventually, an equivalent amount of ION^{π} comes out of $\mathbf{A}^{\pi}$ and goes back to C^{π}. It may come straight from the IEA of an $\mathbf{A}^{\pi}$ node if it accumulated enough ION^{π} by then. If the purchaser doesn't have enough ION^{π} and uses another ION or NC, market-makers are transparently involved to convert the other currency to ION^{π} as the payment goes to C^{π}. Market-makers are likely to charge exchange fees and make the transaction more expensive, which is why purchasers have an incentive to join the $\mathbf{A}^{\pi}$ nodes and be able to pay in π's native currency.

The original function of ION^{π} was to underwrite the creation of π. When a unit of π-creation completes its supply-demand life-cycle with a sale, the lifecycle of the ION^{π} units used as payment also ends and that ION^{π} is annulled from ION network. This also prevents C^{π} from double-spending its ION^{π}. The units of ION^{π} being annulled do not have to be the exact same units from when that particular π was created. In other words, ION^{π} units are fungible between themselves.

Bridging Gaps in INFs Connectivity & Capacity

In an ideal scenario where the ION network is perfectly connected an ION economy can work solely with INFs. In realistic scenarios however, $\mathbf{A}^{\pi}$ nodes will not be perfectly connected to C^{π}. Even where they are connected, the capacity of the hop balances may not be enough for all the ION^{π} that C^{π} wants to spend.

Market-making can address connectivity and capacity issues instantly by buying an ION where it cannot flow and selling it across the gap. The IEA of C^{π} is aware of all market-makers servicing an ION^{π} and can choose the best rates automatically. The market-making process is straightforward if both the payer and payee are using IEAs. However, market-making could also be implemented indirectly through a proxy credit-card. For example, if C^{π} wants to pay someone who does not use an IEA, C^{π} could use the proxy credit card as any other accepted card. The market-maker who issued the proxy card would pay the balance to a conventional bank using Currencies. At the same time, the market-maker would deduct the matching amount of ION^{π} from the IEA of C^{π}. The credit limit of the proxy credit card can be based on the ION contract so that C^{π} can only spend the ION^{π} it is able to issue.

Another way to address connectivity and capacity issues is to create targeted offers and demand whose key purpose is to bridge a gap where new INFs could pass. Unlike market-making, such network-graph augmentation does not require the spending of any intermediary currencies. The basic incentive for nodes engaging in network-graph augmentation is faster clearing of their accounts receivable & accounts payable. For example, in Figure 6 there may be no matches between offers from *P* and demands from *M* at first. However, *M* may decide to purchase something that *P* offers. The incentive for *M* is that a new INF passing downstream towards *P* could clear some balance that *M* owes upstream. Third-party entities may also have incentives to engage in network-graph augmentation. An investor or a government may want to create opportunities at some gap that is unrelated to its projects, only because the network location of that gap prevents INFs from opening up between the project nodes.

Conclusions

An implementation attempt could technically start even with a single ION for a new activity without disrupting existing economic practices. The activities could have a wide economic scope, like types of agriculture or manufacturing, where multiple business entities produce under the same ION label. Reliable ION network market-makers could hide the complexity for anyone not interested in handling ION labels, without excluding them from the ION network economy. The user experience shown in Figure 6 is completely arbitrary and some of it may be unnecessary next to existing business workflows. Going further, it can be argued that with technology trends in automation, bots, analytics and pattern matching, many more IONs can become tractable from a user experience.

The principal benefit of the proposed model is the ability to fund economic activity without pre-existing financial capital, i.e. without dependency on borrowing, savings, taxation, or bank reserve ratios. Each new unit of ION^{π} remains tethered to an activity unit on one end, its demand dynamics on the other end, and it gets annulled when a related supply-demand loop terminates. Combined with the way the model separates the unit-of-account and medium-of-exchange functions, all of this leads to an inherent resilience to inflation and deflation.

Such creation of financial capital leads to novel forms of financing. Towards one end of the spectrum where a sufficiently connected ION network operates with only INFs and without market-makers, a community could self-fund by organizing the network-graph augmentation of its ION network. Towards the other end of the spectrum where market-makers are needed, legacy capital gets an inverted form of investing where capital is disbursed on a micro-level into the demand-side instead of bulk transfers to the supply-side project operators. This offers new mechanisms for transparency and viability analytics. Across the spectrum, these two modes can combine in various hybrid scenarios.

The benefits of the proposed model can also be discussed in terms of the theoretical functions of money: store-of-value, unit-of-account, medium-of-exchange and standard-of-deferred-payment functions. To begin with, pushing the fidelity of monetary decentralization down to individual economic activities produces a standard-of-deferred-payment function that is uniquely separated from the other functions. The standard-of-deferred-payment becomes expressed as redeemable units of the activity. This allows the fundamental price of a unit π to be perfectly stable (always a unit of ION^{π}), and vice versa, the core redemption value of a unit of ION^{π} becomes perfectly stable. Fluctuations in prices are externalized into exchange rates between economic activities. These exchange rates serve as a new numeraire for the unit-of-account function, so that it clearly separates from the medium-of-exchange function (expressed as units of IONs). The value of such separation, which has been challenging to achieve, was discussed in the Related Works section. Lastly, the store-of-value function comes directly from the immutable claim each ION has to the unit of product or service it underwrites. This means the value it stores is rooted in something real, a property of commodity-based systems such as the gold standard. However, unlike such systems, IONs do not suffer from scarcity that can limit growth and induce hoarding.

Future Work

Volunteering, philanthropic or non-profit activities can often have recognizable economic impact, which nevertheless fails to contribute to their financing ability. This could be because the benefit is difficult to quantify without something that can reveal network effects, like multi-hop perspectives. It could also be due to lack of legacy liquidity.

One example are unpaid programming volunteers for open-source projects, like Linux which powers much of the commercial Internet and internal business networks (Finley, 2016). It may be possible to form an $\mathbf{A}^{\pi}$ sub-economy (e.g. Linux supporters) without requiring the $\mathbf{A}^{\pi}$ nodes to purchase anything from C^{π} (e.g. Linux coders). If $\mathbf{A}^{\pi}$ nodes begin to accept a certain amount of ION^{π} in future payments made to them, and if the $\mathbf{A}^{\pi}$ sub-economy is interconnected enough, then ION^{π} would not only be pulled into $\mathbf{A}^{\pi}$ but could circulate in there for any amount of time as generic payment instrument when $\mathbf{A}^{\pi}$ members transact with each other on anything.

Unlike the basic application presented in this paper where a purchase closes the supply-demand loop in a simple way, there are obvious challenges with open-ended flows. What happens if $\mathbf{A}^{\pi}$ collectively underwrites more ION^{π} than the volume transacted between $\mathbf{A}^{\pi}$ can utilize? Can the market of ION^{π} rates provide enough information for the supply side at C^{π} to find some equilibrium with the economic capacity of its stated supporters $\mathbf{A}^{\pi}$? Can we imagine a smart contract that could annul units of ION^{π} when some tangible impact from π is obtained by an $\mathbf{A}^{\pi}$ member?

Applications with less obvious loops can also be considered in philanthropy, government budgeting, or the non-profit sector. Instead of transferring a bulk of capital (a donation, a grant, or a budget allocation) to an operator of project π (i.e. to some C^{π}), a funder could market-make for its ION^{π}. In the worst case, the funder would spend the same amount of money but would get the novel transparency and viability analytics possible with demand-side funding. However, if the funder can also organize the beneficiaries of π into an $\mathbf{A}^{\pi}$ it may be possible to distribute the ION^{π} in a way that does not impede access to π while also getting benefits from the ION^{π} flows, such as much needed impact measurements in these sectors. Further, could the funder tie the ION^{π} flows to other economic development in way that develops financial self-sufficiency for C^{π}?

Finding ways to recognize value creation better and from more human activities is going to become a more pressing challenge as job automation accelerates. This is not only an economic challenge, but a social one as well. Harari (2016) cautions of a rising 'useless class', which could rebel more against irrelevance than exploitation. An economy based on multi-hop transactions can better reveal the relevance of all intermediaries. The greater information capacity in such transaction models can power smarter contracts for computational underwriting of value in social networks.

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