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Community Currency Systems: basic income, credit clearing, and reserve-backed. Models and Design Principles

FRIBIS Discussion Paper - Working Paper by NetFi Research Team

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This paper briefly introduces models and basic design principles of community currency systems from economic and network analytical perspectives. Policymakers, grassroots organizations, and activists can find in this paper the necessary analytical and practical tools to start and enhance their own community currency projects.

Keywords: community currency systems, complementary currency systems, basic income, monetary innovation, economic network analysis, circulation analysis, currency analysis, currency systems
Author roles: T.C. = conceptualization, methodology, original draft preparation, review and editing; E.G. = review and post-editing, S.A. = review and editing; J. L. = review and editing.

1 Introduction

Definition Community currency systems are self-organized means of exchange and means of payments used in parallel to national currencies. The main features reported in the literature are the following (Blanc, 2011; Gómez, 2018a; Gómez & Dini, 2016): they are based on a *community agreement* and a *voluntary acceptance* among users, they are designed by a local institution or a grassroots initiative mainly as a tool for community empowerment, local development, and/or social and humanitarian intervention.

Typology In this paper, three main models are described: credit clearing systems, reserve-backed or convertible currency systems, and basic income currency systems. Credit clearing systems are all those systems designed to clear out debts among members of a predefined group without the use of a national currency (Amato & Fantacci, 2012; Lucarelli & Gobbi, 2016). The three main sub-types are: mutual credit systems (Greco, 2001, 2013; Slater & Jenkin, 2016), mutual banking systems (Gelleri & Stodder, 2021; Studer, 1998), and obligation clearing systems (Fleischman, Dini, & Littera, 2020). Reserve-backed or convertible community currency systems are designed to be exchanged with a national currency. The main intent behind them is charging conversion fees and investing the revenues in the community for provision of public and/or common goods and services (Gelleri & Stodder, 2021). Finally, the basic income currency systems are designed to provide conditional or unconditional income to satisfy basic needs of the local population or only some targeted groups. (Cabaña & Linares, 2022; Martín Belmonte, Puig, Roca, & Segura, 2021).

Empirical findings Only in the last decades, the digitisation of payment systems has been allowing researchers to carry on in-depth empirical studies otherwise impossible. The quantitative empirical analyses of digital community currency systems is proving their relevant role in enhancing the resilience of local economies. A secondary less fungible currency or the existence of an alternative payment channel can *balance* the payment system by reducing the liquidity risk Fleischman and Dini (2021); Fleischman et al. (2020); Zeller (2020). In the case of macroeconomic shocks and seasonal changes, a complementary payment system has been empirical proven to have a so-called *counter-cyclical effect* stabilising the whole economy (Stodder, 2000, 2009; Stodder & Lietaer, 2016; Studer, 1998). Furthermore, the increased amount of liquidity in the local economy and the process of community empowering can unlock unused productive capacities by unleashing a so-called *local multiplier effect* (De la Rosa & Stodder, 2015; Groppa, 2013; Iosifidis et al., 2018). Finally, in contexts suffering a permanent lack of liquidity or cyclical crises, community currency systems have been effective in enhancing social and humanitarian interventions by boosting endogenous local development and empowering local communities (Fare, de Freitas, & Meyer, 2015; Gómez, 2018b; Martín Belmonte et al., 2021; L. Ussher, Ebert, Gómez, & Ruddick, 2021; Zeller, 2020).

Contribution The main contribution of this paper is the description of the necessary strategies and design principles to introduce a community currency system. In Section 2 and 2.1, the main topological analytical tools are reported. These are preliminary analytical tools necessary for the initial design of a currency system which should be based on an appropriate understanding of the structure of the local economic network. In Section 3, the main issues of liquidity distributions are described with respective solutions. In Section 4, the main models of community currency are reported with examples on how they deal with issues related with liquidity distribution. Finally, in Section 5 the main design principles are described and a fourth principle (Section 5) is presented with a theoretical justification.

2 Topological analysis

An economic network can be defined as a weighted directed graph $G = (N, L, w)$, where N is the set of nodes, L is the set of link, and w is the set of weights associated to each link. Each directed link from node n_i to node n_j represents a flow of currency from n_i to n_j. Each link is associated to a weight w_{ij}, which is the sum of the value of currency flows from n_i to n_j in a given period of time. The directed graph can be represented as an adjacency matrix A, where $A_{ij} = 1$ if a link goes from n_i to n_j, and zero otherwise.

In-degree and out-degree For each node n_i, it is possible to calculate both the in-degree and the out-degree (Newman, 2018). The in-degree of a node k_i^{in} is the number of all the incoming links to node n_i. While the out-degree of a node k_i^{out} is the number of all the outgoing links from node n_i (see Equation 1). The centrality metric is a normalisation measured by taking the ratio of the observed value and the maximum possible value. In economic terms, the in-degree centrality represents a degree of monopolistic market power, while the out-degree is a measure of monopsonistic market power.

$$k_i^{out} = \sum_{i=1}^{n} A_{ij};\ k_i^{in} = \sum_{j=1}^{n} A_{ji} \tag{1}$$

The total revenues R_i of a node n_i can be calculated as the weighted in-degree; while the total expenses E_i can be calculated as the weighted out-degree (see Equation 2).

$$R_i = \sum_i w_{ji} A_{ji};\ E_i = \sum_j w_{ij} A_{ij} \tag{2}$$

Betweenness centrality For each node n_i, let b_i^{st} be 1 if node n_i lies on the shortest path from node n_s to node n_t, and 0 otherwise or when the path does not exist (Newman, 2018). The shortest path is the shortest distance between a given pairs of nodes. Let b^{st} be the total number of shortest paths from

n_s to n_t, and n^2 the total number of ordered node pairs, the betweenness centrality of n_i is given by Equation 3. By convention (Newman, 2018), if b_i^{st} and b^{st} are both zero, then $b_i = 0$.

$$b_i = \frac{1}{n^2} \sum_{st} \frac{b_i^{st}}{b^{st}} \tag{3}$$

In economic terms, betweenness centrality is a measure of brokering market power. In some cases, local versions of it can be preferred to detect and measure degree of brokering power in different components of the same network (Gregory, 2008).

Directed cycles A *cycle* is a simple path which does not pass more than once to any node except the starting one. Considering a distance-based individual utility in a directed network with myopic players and one-way cost flow structure, according to different cost link structures, directed cycles or empty networks are the most Pareto-efficient and Nash stable (Jackson, pp. 384-388).

Every *cycle* in a currency network is a *balanced payment sub-system* because all the obligations can be discharged simultaneously (Fleischman & Dini, 2021). Furthermore, cyclic structures in an economic network increase the performance of all the nodes involved, and for the entire network, by triggering a *local multiplier effect* (Iosifidis et al., 2018).

In a directed network, it is possible to identify *weakly* and *strongly* connected components (Newman, 2018). In a *weakly connected component*, every node can reach any other node only by ignoring the direction of links. In a *strongly connected component*, every node can reach any other node by considering the direction of links. This implies that every node in it has at least one incoming and one outgoing link. Moreover, every node is involved in *cycles* of lengths from a minimum of 2 to a maximum equals to the size of the strongly connected component. A directed network is usually shaped as a *bow-tie* (Glattfelder, 2019): a strongly connected component with a set of incoming links (*in-tendrils*) and one of outgoing links (*out-tendrils*) (see Figure 1).

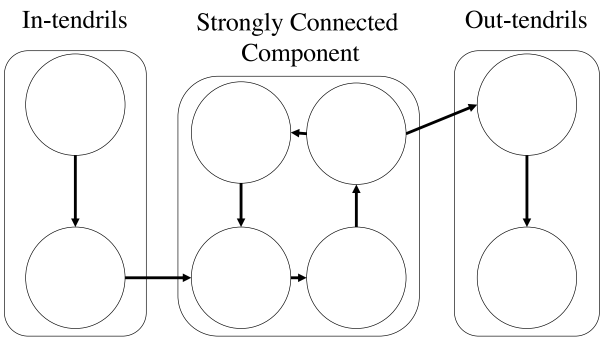

Figure 1: Simplified illustration of a *bow-tie* directed network.

2.1 Economic implications

Liquidity distribution The topology of the economic network has several implication on the liquidity distribution of a payment system. The liquidity distribution can be *circular* when payments can be settled in a specific order, *gridlocked* when payments can be settled only simultaneously, and *deadlocked* when payments can be made only by adding liquidity to at least one of the participants (Leinonen, 2005).

In an economic network, the currency flowing circularly is represented by strongly connected components, at any given point in time. Gridlocks and deadlocks are represented as *in-tendrils* and *out-tendrils* attached to them. In economic terms, *out-tendrils* are accumulating currency without spending and *in-tendrils* are only spending without purchasing. The presence of *in-tendrils* and *out-tendrils* indicates that the currency is not *circularly* flowing in the economic network creating deadlocks and gridlocks in the payment system.

From an economic perspective, *out-tendrils* can be associated to agents who can offer goods and services demanded by the economy, but there is a *deficiency* of supply to satisfy their needs. On the contrary, *in-tendrils* can be associated to agents who can satisfy their needs in the economy, but they cannot offer something considered valuable in it - i.e., *deficiency* of demand. In economic literature, the first problem is a lack of *backward linkages*, while the second is a lack of *forward linkages* (Hirschman, 1958; L. Ussher et al., 2021) in the supply chain. The lack of *backward linkages* causes accumulation of currency, while *forward linkages* causes accumulation of debt or even defaults.

Market power Degree and betweenness centrality affect price formation and liquidity (and income) distribution in any economic network. A degree or betweenness centrality increase predicts an increase of individual income (Cardoso et al., 2019; Cassese & Pin, 2018). In fact, the absence of competitive node-disjoint paths is associated with an increase of prices and an increased average path length is associated to an increase of costs (Cardoso et al., 2019). This increase of prices is called *mark-up*, and it is associated with the extent of market power which the agent has and exploits in the economic network. Even though more research is needed on this matter, it could be possible to argue that *demand-pull* inflation is mostly caused by topological features of the economic network, in line with studies of capital as a form of power which tends towards centralization (**?**).

In a *cyclic* network every node has the same out-degree, in-degree, and betweenness centrality. In other words, if the economic network is represented by a *cycle*, every node would have the same market power. Real economic networks are not structured as *cycles*, but it is possible to identify strongly connected components which contain them. Inside a strongly connected component, nodes are involved in many different *cycles* of different lengths, and therefore, market power distribution still can be very heterogeneous.

3 Balanced payment system

Analyzing the topology of an economic network includes the detection of strongly connected components, *in-tendrils*, and *out-tendrils*. These three topological elements are associated to *circularity* in the payment system, *gridlocks*, or *deadlocks* (Leinonen, 2005). The presence of *gridlocks*, or *deadlocks* can be the result of missing *backward* and *forward* linkages in the local supply chain (Hirschman, 1958; L. Ussher et al., 2021). In the long run, they create imbalance in the payment system with accumulation of liquidity on one side and of debt or defaults on the other side. In the community currency literature, several strategies to balance the payment system are described and some of them are reported in this section.

Gridlock A *gridlock* is a situation in which the payment system can work only if the transactions are carried out simultaneously. This means that the solution of a *gridlock* is about matching deficiency of demand and supply by trying to create the missing linkage in the supply chain. In practice, it means that an institution is in charge of *matchmaking* nodes in the *out-tendrils* and those in the *in-tendrils* of the strongly connected component. Ideally, the former group should try to supply the last one. These kind of operations are reported in the literature about credit clearing systems (Amato & Fantacci, 2012; Fleischman et al., 2020; Gelleri & Stodder, 2021; Greco, 2001, 2013; Lucarelli & Gobbi, 2016; Slater & Jenkin, 2016; Studer, 1998).

Deadlock A *deadlock* is a situation in which the payment system can work only by adding more liquidity in it. In simple words, this means that even trying *matchmaking* nodes in deficiency of supply and demand does not improve the situation. Eventually, they cannot find anything to exchange among them. A *functional deadlock solution* is a strategy that does not require any intervention in the structure of the economic network, while a *structural deadlock solution* does.

There are four main strategies described in the literature as *functional deadlock solutions*. The first solution is about allowing the conversion to a national currency in some selected cases (Gelleri & Stodder, 2021; Martín Belmonte et al., 2021; Mattsson, Criscione, & Ruddick, 2022; Rivero Santos, 2017; Ruddick, 2011; Ruddick, Richards, & Bendell, 2015; L. Ussher et al., 2021). The second solution is about allowing an internal redistribution through local savings and investment groups (Mattsson et al., 2022; L. Ussher et al., 2021). The third solution is about implementing an internal regulation by fixing debt and/or credit limits, imposing a fixed repayment schedule for debt positions and related penalties, and/or even the exclusion of some members (Linton, 1994; L. Ussher et al., 2021; L. J. Ussher, Haas, Töpfer, & Jaeger, 2018). Finally, the fourth solution is the obligation clearing, which means to cancel out the minimum amount of common outstanding debt in the payment system and paying only what is left (Fleischman & Dini, 2021).

A *structural deadlock solution* requires an *asset-based community development strategy* (ABCD) (Bruursema, 2015; Woodward, South, Coan, Bagnall, & Rippon, 2021) which is based on mapping, reallocating, or activating local used and unused resources. The community can identify and activate unused capacities (e.g., unused workforce, abandoned lands, etc.) by investing into a new economic activity able to create both missing *backward* and *forward* linkages. Another possibility is the reallocation of an existing activity to reach the same goal - i.e., training a producer to fulfil the needs expressed by those accumulating an excess of surplus. These kind of operations may require the community investment planning on the provision of public and common goods and services, collective purchases, and/or acquisition and share of private properties (Gelleri & Stodder, 2021; Mattsson et al., 2022; Rivero Santos, 2017; Ruddick, 2011; Ruddick et al., 2015; L. Ussher et al., 2021).

4 Models

In this section the main models used to design community currency systems are reported. Every model presented is described by providing examples of existing projects. Particular attention is given to those strategies adopted to balance their payment systems.

4.1 Credit clearing systems

Credit clearing systems are all those systems designed to clear out debts among members of a predefined group without the use of a national currency (Amato & Fantacci, 2012; Lucarelli & Gobbi, 2016). The three main sub-types are: mutual credit systems (Greco, 2001, 2013; Slater & Jenkin, 2016), mutual banking systems (Gelleri & Stodder, 2021; Studer, 1998), and obligation clearing systems (Fleischman et al., 2020).

A mutual credit group is equivalent to a multilateral barter trading system, where members record the value of exchanged goods and services in a common ledger (Linton, 1994; Slater & Jenkin, 2016). Every member starts with an account balance of zero, and she can start purchasing from other members up to a predefined debt limit, or selling to other members up to a predefined credit limit. In this way, the sum of credits and debts is always equal to zero, and within a predefined period of time (e.g., one year) all the accounts need to go back to zero (Littera, Sartori, Dini, & Antoniadis, 2017). The introduction of a strict internal regulation with related penalties has been proved to be effective in some cases (Iosifidis et al., 2018; Littera et al., 2017). In theory, this system can easily scale-up by nesting several groups active in the same geographic area (Slater & Jenkin, 2016).

Mutual credit systems are fundamentally based on the assumption that members are willing and capable of closing their position back to zero after a predefined period of time - i.e., *long-term equilibrium assumption* (L. Ussher et al., 2021). This is equivalent to the economic assumption of *perfect competitive markets*, where the following conditions hold: the *zero-profit condition* is satisfied (see Equation 4), so that the value of demanded products is equal to its supply; agents can take decision using *complete*[1], *unbiased*[2], and *symmetric*[3] information; the social network does not affect the economic behaviour - i.e., absence of social, cultural, and political preferences.

$$\forall i, R_i = E_i \tag{4}$$

The restriction of this assumption is often reflected by the empirical evidences of *defaults* and *imbalances* L. Ussher et al. (2021). In case *gridlocks* and *functional deadlocks*, mutual credit systems can operate only to some extent. In case of *structural deadlocks*, they are usually not designed to collect and invest liquidity to start new economic activity or re-allocate an existing one which could create the missing *backward* and *forward* linkages. Nevertheless, *pure* mutual credit systems are still a very important benchmark in community currency design (see Section 5.

[1] Agents have access and are capable of managing all the necessary information of the (present and future) system to take conscious decisions.

[2] Agents are not affected by cognitive biases, heuristics, and other relevant psychological factors in taking their decisions.

[3] All agents are provided with the same quantity and quality of information.

Examples Sardex in Sardinia (Italy) is an example of mutual credit system among local businesses. Sardex corporation operates as matchmaker and supervisor of transactions among the members by controlling of *gridlocks* and *functional deadlocks* (Iosifidis et al., 2018; Littera et al., 2017). Local exchange trading systems (LETS) and community exchange trading systems are example of mutual credit systems among individuals with a huge variety of self-regulating techniques (Linton, 1994; North, 2010; Slater & Jenkin, 2016).

There are other particular types of credit clearing derived from the *pure* mutual credit systems which are worth mentioning here. One particular type of mutual credit system is the so-called *timebanking*, where one hour of service is always equal to one credit (Cahn & Rowe, 1992; North, 2010). A mutual banking credit system is a system where the access to local currency is provided only as a loan given by a central community institution - i.e., WIR Cooperative Bank in Switzerland (Gelleri & Stodder, 2021; Stodder, 2000, 2009; Stodder & Lietaer, 2016; Studer, 1998). An obligation clearing agency is an institution in charge of setting off debts in an economic network by operating a matchmaking - e.g., AJPES in Slovenia Fleischman and Dini (2021); Fleischman et al. (2020). Finally, the Sarafu system in Kenya is inspired by a mutual credit system, and it is regulated in a way that can potentially control for *functional* and *structural* deadlocks (Mattsson et al., 2022; L. Ussher et al., 2021).

4.2 Reserve-backed or convertible currency

In a convertible community currency system, the presence of *in-tendrils* and *out-tendrils* is exploited by introducing the possibility to convert the community currency with the national tender, and vice-versa. The conversion fees can be used to do interventions in the economy and intervene on *structural deadlocks*.

Examples The Chiemgauer currency system is one of the most well-known cases of convertible community currency. It started in 2003 as a project launched by the local Waldorf school in the Chiemgau region (Dittmer, 2013). Chiemgauer is a non-profit organization located in Traunstein (Bavaria, Germany), and every member paying an annual membership has the right to get a vote for the assembly (Gelleri & Stodder, 2021). In 2019, there were 419 businesses participating in the local economic network (Zeller, 2020). The Chiemaguer currency has the following features (Gelleri & Stodder, 2021): it is accepted among local businesses in parity with euros, but the percentage of acceptance is subjective; simple citizens can buy the community currency by paying a small conversion fee, but they cannot exchange them back to euros; local businesses can also exchange the community currency to euros by paying a small conversion fee; local non-profit organizations receive the revenues of the conversion fees (3% in community currency or 2% in euros). An expiration date and a negative interest rate is also applied on the currency (Dittmer, 2013; Gelleri & Stodder, 2021; Zeller, 2020).

4.3 UBI / Basic income currency

The adoption of basic income community currency systems has been tested in the last years as form of social, humanitarian, and local development intervention (Coop, n.d.; Group), 2021; Martín Belmonte et al., 2021; Rivero Santos, 2017; Rodrigues & Neumann, 2021). In principle, a basic income currency does not have tools to deal with *gridlocks* and *deadlocks* of the payment system. Nevertheless, the literature reports experiences which allowed for a selective conversion of the community currency to a national tender - i.e., *functional deadlock* solution (Coop, n.d.; Group), 2021; Martín Belmonte et al., 2021; Rodrigues & Neumann, 2021). In very few cases, the basic income was integrated with other strategies to deal with the imbalance of payment systems and *structural deadlock* especially (Rivero Santos, 2017).

Examples Circles UBI is a worldwide platform designed to issue an universal and unconditional basic income in Circles to every community in the world. The main features are the following (Coop, n.d.): every new member needs to be validated by other three existing members in order to be able to exchange Circles; every user receives 1 Circles every hour, every issued Circles is subject to a negative interest rate of 7%/year - i.e., *demurrage*. It was launched in October 2020, and since July 2021, 16 businesses in Berlin are allowed to cash-out as way to solve local *deadlocks*.

The REC (Real Economy Currency) in Barcelona (Martín Belmonte et al., 2021), the Gyeonggi in Korea (Group), 2021), and the Mumbuca in Brazil (Rodrigues & Neumann, 2021) are all unconditional basic income currency projects, albeit targeting only some groups of the local population. Even in these cases, the presence of *gridlocks* and *deadlocks* is controlled through selective conversion to the national currency.

Finally, RASTRU (*Red Asturiana de Comunidades de Trueque or 'Asturian Network of Barter Communities'*) was a pilot project active from 2012 to 2018 adopting a conditional basic income but with very peculiar features (Rivero Santos, 2017). The payment system integrated a mutual credit system, a basic income currency, and a one-way convertible currency. The main goal was to guarantee food sovereignty to the local community by giving members direct control over the local production of food and guaranteeing access to everyone in need. The community currency was designed to address community investments towards common lands and collective agricultural projects - e.g., community-supported agriculture models, training for farmers, purchase of tools, etc.

5 Design principles

In the previous sections, the main topological features of economic networks, the issues related with liquidity distributions, and the main models of community currency were described. In this section, the main design principles for community currency systems suggested in the literature are summarised, and an additional principle is introduced within an appropriate theoretical framework.

The first principle is the detection and creation of missing *backward* and *forward* linkages L. Ussher et al. (2021) which can be visualised in the network as *in-tendrils* and *out-tendrils*. This operation is equivalent to the detection of *gridlocks* and *deadlocks* in the liquidity distribution. Gridlocks can be solved by *matchmaking*. Deadlocks can be solved by adopting *functional solutions* which do not affect the topology of the economic network, or *structural solutions* (see Section 3).

The second and third principles are corollaries of the first one, here they are only briefly reported. The second principle is about diversifying the local production which guarantees economic resilience in the long run (L. Ussher et al., 2021). The third principle is the so-called *import-substitution* (Martín Belmonte et al., 2021) which implies the creation of a local economy as self-sufficient as possible. A fourth principle is introduced in the next section by describing the conditions for a *currency issuance control* within an appropriate theoretical framework.

Perfect competitive economic network Mutual credit systems are based on a *long-term equilibrium assumption*, which is equivalent to assuming a *perfect competitive market*, both as initial and final stage. This is a *perfect egalitarian state* where every agent produces and consumes the same value of products (see Equation 2), every agent can equally access and process the same quantity and quality of information, and there are no social preferences (see Section 4[*Credit clearing systems*] for more details). Nevertheless, mutual credit systems remain a benchmark for understanding the fundamental structure of any balanced payment system. The design of a mutual credit system is based on the assumption that at $t = 0$ the economy is already at an *egalitarian state*, thus the *zero-profit condition* is applied already at the initial design (see 4.

A *perfect competitive market* implies that everyone has the same level of market power (see Subsection 2.1). From a topological point of view, everyone has the same in-degree, out-degree, and betweenness centrality (see Equation 5). In such situation, no one can raise a *mark-up* without paying back the consequences afterwards. Therefore, the *perfect competitive economic network* is a network where all the nodes are involved in the same number of *cycles* (see Figure 2). In fact, in this particular case, the in-degrees are equal to the out-degrees for every node n_i, $\forall i : k_i^{in} = k_i^{out}$). By (5), the *perfect competitive economic network* is defined by the equivalence $k^{in} = k^{out}$. In a *perfect competitive market*, the conditions expressed in (5) should hold. This means that aggregated demand and aggregated supply can only be equal in a *perfect competitive economic network* (see Proof 1 in Appendix)(see Figure 2). Mutual credit systems are designed to work on *perfect competitive economic networks* which can indeed theoretically scale up by nesting different mutual credit groups (see Slater and Jenkin (2016)) or *cycles*. In those systems, liquidity is not even necessary as far as a public ledger is available. In fact, users could easily offset their debts as if they were in a multilateral barter trading system.

$$k_i^{in} = k^{in}; k_i^{out} = k^{out}; b_i = b \tag{5}$$

Initial allocation In a mutual credit system, the total amount of debt limits allocated to each member is equal to the total amount of initial currency supply $M_{t=0}$ which is equally distributed to each member (same for basic income currencies). At the beginning of $t = 0$, the optimal amount of currency supply $M_{t=0}$ at $t = 0$ to be issued should be equal to the expected value of aggregated demand $\mathbb{E}(Y_{t=0}^D)$

at $t = 0$, which needs to be satisfied by the value of aggregated supply produced in the period before $t = -1$, $Y^S_{t=-1}$(see Equation 6).

$$M_{t=0} = \mathbb{E}(Y^D_{t=0}) = Y^S_{t=-1} \tag{6}$$

This initial equilibrium condition is valid for any model of community currency system. This is especially relevant for mutual credit and basic income currency systems, where the amount of currency to supply (or debt limits) to issue is usually arbitrarily decided.

Further steps At $t = 1$, the distribution of currency in the economy $M_{t=1}$ is equal to the initial allocation $M_{t=0}$ plus the difference between what was actually sold and demanded by each individual (Equation 7).

$$M_{t=1} = M_{t=0} + [Y^S_{t=-1} - Y^D_{t=0}] \tag{7}$$

In a *perfect competitive economic network* (see Paragraph 5, the aggregated supply is equal to the aggregated demand ($Y^S_{t=-1} = Y^D_{t=0}$). In other words, every individual is able to earn as much as she spends (Equation 4). This implies that no additional injection of liquidity is necessary ($M_{t=1} = M_{t=0}$). This is valid as far as the value of aggregated supply $Y^S_{t=0}$ produced at $t = 0$ is equal to the liquidity already present in the system $M_{t=1}$, that is

$$M_{t=1} = Y^S_{t=0} \tag{8}$$

If the economy is not structured as a *perfect competitive economic network*, then *in-tendrils* and *out-tendrils* create *gridlocks* and *deadlocks* in the payment system (see Section 3). This situation should be solved by matchmaking *gridlocks*, and/or finding *functional* or *structural* solutions for the *deadlocks*. In other words, missing *backward* and *forward* linkages should be created L. Ussher et al. (2021).

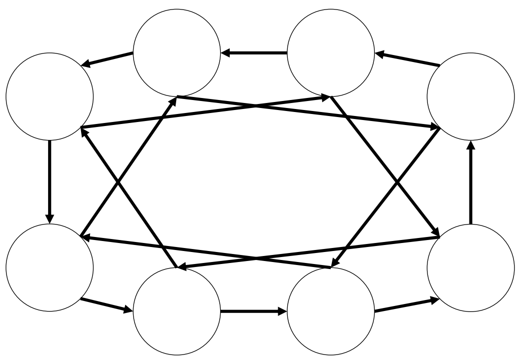

Figure 2: Example of *perfect competitive economic network*. Every node is involved in the same number of cycles.

Fourth principle Generalising the previous results, the fourth principle describes the *currency issuance control* which strictly depends on the topology of the economic network (see Section 5). Nevertheless, in a *perfect competitive economic network* where *gridlocks* and *deadlocks* of liquidity are absent, the general condition is expressed by (9), where the value of supply produced up to $T - 1$ should be equal to the amount of currency supplied at time T.

$$M_T = \sum_{t}^{T-1} Y^S_t \tag{9}$$

The literature on community currency systems also reports the application of a decay or depreciation rate, *demurrage*, negative interest rate, or simply an expiration date on the currency supply which is equivalent to it (Gelleri & Stodder, 2021; Ruddick, 2011; Ruddick et al., 2015). The idea was firstly inspired by Gesell and Pye (1958) and justified by the design of a community currency as a complementary medium of exchange instead of a speculative or saving tool. Even though not usually explicitly stated, the application of an expiration date on mutual credit systems follows the same logic. Following this approach, the Equation 9 becomes

$$M_T = \sum_{t}^{T-1} (1-r)^t Y_t^S \tag{10}$$

where r is a constant depreciation rate applied to the value of aggregated supply. At each point in time T, the optimal amount of currency supply M_t is the discounted future value of aggregated supplies offered in the market before time T. Considering the loss of value of most of products, this is a reasonable assumption. Gesell and Pye (1958) justifies the depreciation rate by looking at the decay of products in the food sector. The estimation of such decay rate should be done by looking at the intrinsic qualities of the products exchangeable in the market.

6 Conclusion

In this paper, the necessary analytical tools, models, and design principles for community currency systems are reported and explained with rigorous details. This paper can help policymakers and activists to correctly design a community currency system by analysing the necessary features of the local economic network.

In Section 2 and 2.1, the main topological analytical tools are reported. These are preliminary analytical tools necessary for the initial design of a currency system which should be based on am appropriate and holistic understanding of the local economic network. In Section 3, the main issues of liquidity distributions are described with respective solutions. In Section 4, the main models of community currency are reported with examples on how they deal with issues related with liquidity distribution. Finally, in Section 5 the main design principles are described and a fourth principle (Section 5) is introduced within an appropriate theoretical framework.

The analytical tools, models, and design principles discussed in this paper assume a particular relevance nowadays. The innovation of digital technologies can indeed support new forms of economic interaction. As an example, the introduction of distributed ledger technologies, such as blockchains (Zhang & Jacobsen, 2018), have been discussed and tested in the community currency field (Coop, n.d.; Mattsson et al., 2022; L. Ussher et al., 2021) by opening new challenges on their technological design (Rodrigues & Neumann, 2021). Further analyses on the technological design principles is left for a future work.

Concluding, the most important contribution of this paper is the theoretical framework supporting the implementation of community currency systems. The introduction of a community currency system can be used to balance the local payment system - i.e., solving *gridlocks* and *deadlocks*. In such a way, community currency systems can also help to efficiently allocate resources in order to satisfy local basic needs in an inclusive, decentralised, fair and democratic manner. Their efficiency on this regard has been successfully tested already in several humanitarian projects (Martín Belmonte et al., 2021; Mattsson et al., 2022; L. Ussher et al., 2021; Zeller, 2020). In particular, this paper reports a possible theoretical framework necessary to explain the the effectiveness of community currency systems in reducing the liquidity risk (Fleischman & Dini, 2021; Fleischman et al., 2020), stabilizing the economy (Stodder, 2000, 2009; Stodder & Lietaer, 2016; Studer, 1998), and boosting a local multiplier effect (De la Rosa & Stodder, 2015; Groppa, 2013; Iosifidis et al., 2018; Martín Belmonte et al., 2021).

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Competing interests

Julio Linares is founding member of Circle Coop e.G. in Berlin, Germany. Other authors have no competing interests to declare.

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Appendix

Proof 1 In a *perfect competitive market* everyone has the same level of market power, as defined by Equation 5.

$$k_i^{in} = k^{in}; k_i^{out} = k^{out} \tag{11}$$

Therefore, the value of aggregated supply and the value aggregated demand can be defined as following

$$Y^S = \sum_{i=1}^{n} w_i k^{in}; Y^D = \sum_{i=1}^{n} w_i k^{out} \tag{12}$$

By imposing the long-term equilibrium condition, aggregated demand should be equal to aggregated supply, $Y^S = Y^D$ (5). Therefore, the sums of w_i cancel out and the final result is

$$k^{in} = k^{out} \tag{13}$$

which is the necessary condition for a *perfect competitive economic network* (see Figure 2, as an example).
□

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