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Complex Systems Modeling of Community Inclusion Currencies*

By Andrew Clark,† Alexander Mihailov,‡ and Michael Zargham §

This paper proposes a complex dynamic system subpopulation model for the construction and validation of a novel form of local complementary currency, namely the Grassroots Economics Foundation's Community Inclusion Currency (CIC) implemented recently in Kenya. First, we highlight that CICs can act as a local liquidity-provision institutional device in poor or isolated economic regions, thereby serving as a market-based mechanism to alleviate poverty. Second, we elicit 50 heterogeneous utility types according to observed transactions behavior in our rich data set, i.e., via revealed – and recorded – preferences, and build a corresponding model and simulation at a meso-economic level.
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I. Introduction

Since the earliest primitive societies, humans across the globe have used various means to intermediate the exchange of goods and to store value, thereby saving and transferring purchasing power across time. For centuries, economists have studied these diverse and evolving forms of money, whether stones, shells, pieces of clay or metal, gold and silver coins, banknotes, paper currency – and even cigarettes used for these purposes in concentration camps [Radford, 1945]. It is now widely accepted that the key function of money has been to provide liquidity for trade as well as durability for preservation of accumulated wealth. What all of these variations of medium of exchange have in common is trust among their users to represent value, and this is also acknowledged as the irrevocable attribute of anything (material or digital) that could possibly serve as money.

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A very recent form of such a medium of exchange, without wide-spread use or popularity thus far, is what has become known as 'community inclusion currency' (or CIC), itself a variant of the more generic term 'community currency', or synonymously, 'complementary currency', 'parallel currency' and 'local currency' [Amato and Fantacci, 2020][1]. The purpose of our paper is to present its potential and to assess its advantages and disadvantages, by focusing on a particular case study of an empirical socio-economic interest, namely, the *Grassroots Economics* initiative developed by Will Ruddick in poverty-stricken regions of present-day Kenya [Ruddick, 2020]. In doing so, we begin by situating this new CIC concept in context, outlining the main definitions and mechanisms that could support its application, in particular with respect to the operation of *Grassroots Economics.*

In their handbook chapter we just cited, [Amato and Fantacci, 2020] provide a broad overview of the various forms of complementary currencies throughout history and review current proposals to introduce parallel currencies. Community currency is a form of *scrip*, i.e., any substitute for legal money, issued by a group with some common bond, feature, location or function. Its main objective, with particular view to our exploration that follows, is to maintain liquidity in a community when the national currency is in limited supply. Under such circumstances, the scrip is designed to meet the specific needs of the users.

Historically, community currencies have the following distinguishing characteristics [Ruddick, 2020]:

1) are issued by a community organization;
2) cannot be used outside the community;
3) bear zero interest rate (like money);
4) encourage the community to help each other.

Community currencies meet two of the four functions of money, namely, medium of exchange and unit of account. They do not meet the other two, those of standard of deferred payment and store of value, except for the near term.

Although rigorous economic analysis around privately-issued currency is still to come, the evidence so far suggests that the public, at least in times without economic turbulence, will accept a privately-issued currency as a complement or even (temporary) substitute for government-issued currency without the need for a discount. Our present study tries to delve into a modern, technology-based way to organize and exploit, even if as a transitional arrangement only, a community inclusion currency in local areas and societies where it may be of benefit.

In this paper we contribute to the emerging blockchain literature from a perspective that synthesizes work in computer science and systems engineering with

[1]However, there may be an alternative viewpoint that community currencies constitute indeed the earliest form of money, dating back to primitive societies before the minting of gold and silver coins. We would not disagree with either interpretation.

work in economics. These 'within discipline' approaches to examine, emit, maintain and operate monetary standards, in their old and new forms, have generally developed in separation and without much interaction and cross-influence. It is strange to see nowadays that, when reading such type of studies with the aim to seek integration and synthesis, different terminology is often used to denote the same phenomenon or notion. We shall hereafter provide both the computer-science/systems-engineering and economic/monetary terminology in a way that tries to bridge the gap across the two disciplines.

Beyond such 'linguistics', and more importantly and precisely, we contribute to the literature on grounding the now exploding CIC studies into more economics, in both a theoretical and a quantitative sense. To do, we simulate the *Grassroots Economics* foundation's CIC implementation in Kenya, employing a graph-based dynamical system model from computer science adapted to uses and conclusions that are standard in monetary economics. Our aim is to provide rationalization for this particular CIC implementation based on economic logic, cost and benefit at the meso-level (i.e., in-between conventional micro- and macro- studies in economics), essentially eliciting preferences from behavior encoded in the dataset of real-time transactions.

The paper is further organized as follows. We begin, in section II, by outlining the closest related literature, while section III presents our modeling approach. Section IV then walks the reader through the model blocks, providing technical detail as well as economic intuition with regard to their internal structure and external links. Section V summarizes in a graphical sequence the main results from our simulation runs, and section VI concludes. For replication purposes, our data and code is available at GitHub, namely at: `https://github.com/BlockScience/Community_Inclusion_Currencies/tree/paper`

II. Literature Review

We split this section into four subsections, each reviewing briefly the following aspects related to our study: (i) popular historical cases of script usage; (ii) the analogy of CICs to a sort of local or regional currency board; (iii) the typical failure of foreign aid for development provided by governments, international organisations and NGOs, and hence the need for a complementary private market-based mechanisms as those offered by CICs; the simulation software for dynamical systems, with a focus in economics and computer science. We highlight them in this order next.

A. Various Forms of Scrip

Scrip has a long history of use in many different countries when the legal tender was lacking, insufficient or inflated. In some instances, such as with US mining and logging towns, company scrip was acceptable at only-company stores, and discounted at such a rate that it made individuals entirely dependent on the company they worked for, ensuring their 'allegiance'. Scrip, if available for redemption to currency, was in general converted at an exchange rate significantly below face value. A well-known example in Austria during the Great Depression of the 1930s was the so-called Wörgl currency (see, e.g., [Greco, 2002]). This scrip took its name from the town which began issuing it in July 1932, but was more precisely referred to as 'labor certificates'. The latter author bases his article on three original reports and concludes that the Wörgl currency improved the financial condition of the local (parish) government that issued it as well as the general health of the local economy during the time it was allowed to circulate.

Scrip in modern times has also had some successful uses, specifically in the form of Canadian Tire Dollars, gift cards and gift certificates. Canadian Tire Dollars are a form of intermediation between government currency and interest-bearing assets that has been used by customers in the mid-1980s in Quebec [Eichenbaum and Wallace, 1985]. Another long-lasting example is the so-called WIR Bank, which was founded in Zurich, Switzerland, in 1934 as the Economic Circle Cooperative, a large-scale mutual credit clearing system that has survived for almost a century. Not much was known about its history and operations until the late 1990s, when Economics Professor Tobias Studer of the University of Basle published his book, *WIR in unserer Volkswirtschaft* (translated as *WIR and the Swiss National Economy* [Studer, 1998], [Studer, 2006]). One of the conclusions Studer reaches is that the WIR system serves not only its own membership, but also the entire economy; the main reason behind is that, similarly to any other barter trade arrangement, it supplements conventional economic trade and thereby facilitates jobs-creating transactions that otherwise would not materialize.

But one does not have to go much back into history: the Global Financial Crisis (GFC) of 2007-2009 has discredited the official banking and monetary systems and has sparkled the proliferation of private cryptocurrencies (for an overview of our own and links with money and central banking, see [Clark and Mihailov, 2019]) and community interest currencies (yes, another CIC acronym, replacing 'inclusion' with 'interest' in the middle). Among the most popular and successful examples is the Bristol Pound, set up by a group of campaigners and financial activists in 2012. This scheme was a network of over 2000 individuals and independent businesses preferring to use both digital and paper local currency to trade in Bristol, keeping this CIC circulating inside the city and thus energizing the regional economy. The digital currency ran until July 2020, when it was retired to make way for a new scheme, Bristol Pay. Paper Bristol Pounds continued to circulate until their expiry in September 2021. The website of this organization, `https://bristolpound.org/`, reports that:

"Today, if you make a payment using your card or your phone, a small percentage of the sale leaves our city in transaction charges. It might not sound like a big deal, but it's been estimated that these charges total £60 million leaving Bristol per year! We want to keep as much of that money in Bristol as we can, by encouraging everyone in Bristol to pay with our new, non-profit payment platform.

Any profits we make will be reinvested in social and environmental projects in the city."

This quote shows clearly another, additional purpose of such community or complementary currencies compared to the national currencies, namely a concern of the local community (sort of patriotism or regionalism) that the stock of money keeps circulating locally rather than 'leaking out' into the national economy. Such an opportunity of 'leakage' does not, in principle, exist for a national currency, unless it is used as a store of value or medium of exchange legally or illegally in a foreign country (e.g., dollarization, parallel currency, black market). Therefore this feature brings in a useful conceptual distinction of the uses of money in a community, or local, versus national, or legal tender, context.

[García-Corral et al., 2020] is a very comprehensive modern study that first reviews world experiences with CICs (see, in particular, tables 1 and 2, pp. 2 and 3 respectively) and then focuses on the case of the province of Almería in Spain, and three popular CICs there, namely the Pita, the Banco del Tiempo (BdT – or Time Bank), and the town of Almócita, "a small rural town with a total of 169 inhabitants in the province" (p. 6). The study attempts to assess "the feasibility of introducing a complementary currency in a small municipality as a method of sustainable local development". It concludes that "complementary currencies are a tool that can reduce the harmful effects of global monetary and financial crises", since "the single currency model creates a super-efficient monetary system on a macroeconomic scale", but often reveals the lack of resilience in local economies; i.e., "this 'dual feeding' increases the resistance to the effects of the crises, providing stability to the whole system." (p. 18).

Hundreds of community currencies have been created [Lietaer et al., 2012], however the vast majority of them have ceased to be sustainable due to the lack of market acceptance, similar to many cryprocurrency projects nowadays. Without a mechanism for redeeming the community currency back into a trusted means of exchange, the lack of trust in the currency and its utility is often a contributing factor in its demise. One of the other issues with community currency projects has been the inability to trade with other neighboring communities, limiting their potential to promote economic growth. On the positive side, research has found that community currencies can counteract seasonal conditions and increase overall trade [Ruddick, 2020, Stodder, 2000]. In the case of the Bristol Pound, as a form of convertible local currency (CLC) – to add yet another acronym in synonymous usage in the (economics) literature – it appears to be the first modern CLC simultaneously satisfying three defining attributes, namely: (i) to circulate regionally; (ii) to be administered by a credit union; and (iii) to be supported by a local council (see, e.g., [Marshall and O'Neill, 2018]). Yet the same authors, who conducted 27 semi-structured interviews with businesses and other Bristol Pound stakeholders, including economists, report that this otherwise seemingly successful modern CLC is not really driving localization. The key barriers to it were found to be political or institutional in nature. Examples include support for free trade, the free movement of capital, the power of global corporations, and the 'expansionary logic of capitalism'. They conclude that such barriers are unlikely to be influenced by a CLC and suggest that "those pursuing localization should engage in a more active agenda that aims to change government policy and institutions to support an equitable, sustainable economy" [Marshall and O'Neill, 2018], abstract, p. 273.

More recently, the *Grassroots Economics* foundation has introduced a sustainable community currency that has shown that community currencies can be an effective means of fostering economic growth. *Grassroots Economics* is a non-profit foundation that "seeks to empower marginalized communities to take charge of their own livelihoods and economic future."[2] The focus of the foundation is on community development through economic empowerment and community currency programs, and beneficiaries include small businesses and people living in informal settlements and rural areas in Africa and Asia. Its goal is "to improve the lives of those who are most vulnerable". *Grassroots Economics* has implemented community currency programs in 45 locations across Kenya and assisted with 2 in South Africa, thus helping more than 40,000 small businesses, churches and schools take an active role in their own economy and development. Recently, they are joining effort with similar organizations, such as Sempo,[3] in launching CIC trading on a new open source platform across 5 countries.[4] *Grassroots Economics* started with an initial pilot in 2010 called Eco-Pesa [Ruddick, 2011], and the project has later on moved from paper-based currency into digital CICs. The digital pilot began in Q4 of 2018, and in about a year and a half 24,000 registered users and an average of 1,000 transactions per day have been reached [Grassroots Economics dashboard, accessed June 14, 2020].

[2] The information in this paragraph is taken from their website: `https://www.grassrootseconomics.org/`.

[3] This is a digital currency startup based in Australia, `https://withsempo.com`. According to news on their website, in July 2020, this blockchain fintech company has secured €1 million ($1.6 million) in funding from the European Commission to fuel digital aid projects in partnership with Oxfam", `https://www.oxfam.org.uk`. It is summarized further that "Sempo provides a centralized model for distributing aid to people affected by disasters, particularly those who don't have access to a bank account, but do have a smartphone. The startup uses a suite of cryptocurrencies, with one acting as the 'global reserve'. The idea is to get people and stores in remote communities onto the platform, allowing for digital cash purchases at times of crisis." Oxfam, founded in 1942, according to their own website is "a global movement of millions of people who share the belief that, in a world rich in resources, poverty isn't inevitable. In just 15 years, extreme poverty has been halved. 15 more years and we can end it for good."

[4] To learn more about the system and access their open source code, the interested reader is referred to the respective GitHub repository: `https://gitlab.com/grassrootseconomics/cic-docs/-/blob/master/README.md`.

B. Currency Board

To provide a parallel with an analogy, which is well established and widely documented in monetary economics[5] and central banking,[6] community currencies are a form of money and credit standard similar to currency boards.[7] A currency board is a reduced, rule-based monetary policy that operates as if in 'autopilot' mode, because there is no option to provide credit to the national government, the commercial banks or state-owned enterprises. Hence, there cannot be monetization of fiscal deficits, or any other sort of inflationary financing from the monetary authority. By design and rationale, in these monetary regimes the backup of the monetary base on the liability side of a central bank's balance sheet is 100 percent in terms of the international reserves on the asset side. Thus, an increase in the stock of paper currency in circulation is automatic and fully-backed, i.e., equal to the current account surplus generated by the national economy during a particular period that leads to a corresponding increase in the international reserves. This full backing in a currency board regime is, of course, a device designed not to allow nominal depreciation of the national currency (also known in the monetary literature as debasement or demurrage). In such a sense, the national monetary unit operated via a currency board is guaranteed not to lose its value in terms of the currency of the peg, usually a strong and desirable currency worldwide such as the US dollar or the Euro (formerly the German mark).

Prominent success stories of currency board regimes are Hong Kong (since 1983), Argentina (since 1991) and Bulgaria (since 1997) [Hanke, 2002]. Yet in the case of community currencies it is some local authority or private operator that takes the responsibility of circulation and exchange, not the national central bank, and the full backing is in terms of commitments in goods or services, along with collateral on the chain asset.[8]

C. Foreign Aid for Development

On the other hand, the failure of foreign (government or NGO) aid for development purposes has been notorious, and long established in the economics

[5] For a recent classification and discussion of the dominant fields and methods of research in monetary economics, see, e.g., [Arestis and Mihailov, 2011].

[6] For a recent non-technical introduction into the rule-based and discretionary frameworks for formulating and implementing monetary policy as well as their main advantages and weaknesses, see, e.g., [Arestis and Mihailov, 2009].

[7] For a dense analysis of the similarities and differences between a typical central bank and its reduction to a currency board, as well as the evidence on their pros and cons in economic performance, see [Hanke, 2002].

[8] Some community currencies, e.g., the Wörgl, do allow for minimal demurrage, that is, 1 percent per month or 12 percent annually, equivalent for the bearer to paying monthly for a stamp ('relief tax') at the parish hall to prolong the use of his/her Wörgl paper note, and to seignorage for the parish hall issuer – see von Muralt (1934) [von Muralt, 1934] cited, and linked in English translation accessible online, in Greco (2002) [Greco, 2002]. In fact, the Wörgl was a post-mortem implementation of the idea for 'stamped money', that is, money that has a finite life unless stamped at a particular time interval, linked to the controversial economist and entrepreneur Silvio Gesell (1862–1930) – see, e.g., [Onken, 2000, Rosalsky, 2019].

literature [Osterfeld, 1990, Sullivan, 1996, Ovaska, 2003, Williamson, 2009].[9] Our paper unifies this theme with the theme of community inclusion currencies, in an effort to explore and promote the benefits of the latter in remedying the major weaknesses of the former. In developing economies, the availability of the national currency often has a low correlation with the local productive capacity or demand, but is to a large extent influenced by external factors, such as trade deficits, foreign interest rates, national debt, and IMF policies [Ruddick, 2020]. Instead of providing only aid-based programs to help alleviate poverty, using also markets to do so and contribute to achieving sustained growth in developing economies is becoming more common [Cooney and Shanks, 2010]. One of the issues with many aid-based development programs is the flow of aid funds to individuals in low-liquidity areas right back to city centers and financiers, creating a never-ending cycle of liquidity constraints. Similarly to the case of the Bristol Pound in our quote above, the goal of CICs and other market-based approaches to reducing poverty and liquidity constraints in poverty-stricken areas is, thus, to close the loop of net cash outflows by providing an incentives program that keeps the liquidity in local economies.

Within the standard development aid programs, little literature exists on new aid innovations, comparable to the community currencies outlined thus far. [Udvari and Ampah, 2018] state that not all aid is created equal, with some aid not directly beneficial in driving economic growth, while some targeted aid given to drive innovation and create infrastructure has been shown to drive economic growth. Their literature review showed that good governance of the receiving country and the institutional background of the facilitator are two leading indicators for aid effectiveness. [Udvari and Ampah, 2018] also found that innovation funding is currently a small proportion of total aid, but that its impacts on economic growth were positive.

The United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA) operates a Cash and Voucher Assistance (CVA) program, that has expanded as a result of COVID-19 [OCHA, 2021]. The program is using technology, such as voice ID, for fund verification, delivery, evaluation, and monitoring. However, this program does not appear to have any local economy-building incentives built-in. [Aker, 2015] shows in a randomized experiment in the Democratic Republic of Congo that cash transfers are more effective than in-kind transfers. [Hidrobo et al., 2014] finds in a randomized experiment in Ecuador that cash, food vouchers, and food transfers are all effective at improving the quality and quantity of food consumed, however food transfers had the largest increase in calories consumed. The emphasis of community currencies on growing local economies is unique among aid organizations, although as outlined by [Udvari and Ampah, 2018], there are programs, such as the World Bank's Digital Economy Initiative for Africa (DE4A) that aim to grow developing economies through digital

[9] There is also an earlier, and related, literature on government failure in developing countries - see, e.g., [Krueger, 1990].

economy innovation [World Bank, 2021].

D. Computer Simulation

When it comes to dynamic system simulation software, the leading software has been, arguably, MATLAB's Simulink [MathWorks, 1984]. Simulink has been around for over 30 years, and is used throughout industry and academia for digital twins, industrial processes, robotics, to name a few use-case categories. Simulink provides a graphical user interface for model building, simulations, analysis, and verification of models. Simulink models can be exported to C, an embedded system programming language often used for use in industrial applications. There are detailed books on Simulink [Klee and Allen, 2011]. However, as successful and widespread Simulink is, it is a closed-source, proprietary tool. In the distributed ledger technology (DLT) paradigm and ecosystem, open-source software is at a distinct advantage, being able to be shared and integrated without vendor licenses. cadCAD (complex adaptive systems, computer-aided design), in comparison, is a Python-based[10], open-source, unified modeling framework for dynamical systems and differential equation simulations. It is capable of modeling systems at all levels of abstraction from Agent-Based Modeling (ABM) to System Dynamics (SD) with the integration of existing data science workflows and paradigms [Block Science, 2019]. Modeling in cadCAD, despite its relative immaturity, provided the benefits of the open-source community with the ability to seamlessly integrate with the robust Python ecosystem, as well as respecting the DLT ethos and community.

The *Grassroots Economics* CIC project has been created utilizing the emerging field of Tokenomics [Ruddick, 2020], which is a subset of Cryptoeconomics [Voshmgir and Zargham, 2019], to build a type of 'regional currency board'. The studied implementation of the CIC system, which the simulations in this paper are a framework of, uses the 'Bancor protocol', named after Keynes' 1944 Bretton Woods international reserve currency proposal, for the underlying bonding curve and smart contracts [Hertzog et al., 2018. accessed June 14, 2020]. Under the Bancor protocol, a bonding curve, i.e., a curve that defines the relationship between reserve stock and token supply, is used to automatically control the redemption rate of a token into the underlying reserve asset (see, e.g., [Zargham et al., 2019]). This mechanism is, essentially, an automated currency board for the local token, in its role as a complementary (or parallel) currency. In the CIC implementation, xDai [xDa, 2018. Accessed June 14, 2020], a stable coin backed by the US dollar (USD henceforth) at a constant 1:1 exchange rate, serves as the reserve, with CICs being 'minted' at a 4x1 basis – see Figure 1. The CIC whitepaper proposes the ability to link the *Grassroots Economics* Sarafu CIC implementation with other CICs with potentially different reserves [Ruddick, 2020],

[10]Python is an open-source programming language that is used for research as well as many production applications across many industries and use cases.

in order to create a flexible, larger system of interoperability community currencies. Using a blockchain system, the ability of interoperability is increased via automated governance by smart contracts and an open, public ledger for validation: these are the factors that could help contribute to make the CIC project, and other subsequent related community currencies, a success.

According to Ruddick [Ruddick, 2020], the new main sources of CIC price stability are market price arbitrage and collateral systems. In the case of market price arbitrage, by taking advantage of market inefficiencies with the bonding curve, traders and investors can obtain temporary profits while profit margins are exhausted by such arbitrage, or speculation, activity, in effect restoring the equilibrium price and creating price stability for the CIC users in a longer run. This phenomenon is well-known in economics as stabilizing (currency, here) arbitrage, or speculation, leading to the law of one price for each currency – or, in a broader sense, commodity or service – provided there are no distortions or imperfections in the relevant market (which in real-world economies and institutions is rare, though). By connecting the CIC system indirectly – via the xDai stable coin – to the USD, the reserve is stable and can reduce fluctuations in the value of the CIC when, under certain conditions, users withdraw their CIC at the prevailing exchange rate – via the USD – to the national currency. Again, in monetary economics the term 'nominal anchor' describes the role of the reserve (asset) currency here, directly the xDai stable coin and indirectly the USD. Differently from a currency board regime, many funding or sponsoring institutions or organizations can decide to enter into contractual relation with a CIC system and add to its backing, and hence liquidity, by providing the reserve asset, directly or indirectly. For instance, even non-government organizations (NGOs), such as the Red Cross, can distribute – and have distributed – funds to a CIC contract to increase the underlying reserve pool, thus funding an increase in market liquidity as well as efficiency with distribution in rural communities. The latter effect is beneficial, and such a market-based poverty-relief mechanism via CICs appears superior relative to standard humanitarian aid, which provides currency to individuals, but often this currency is used to buy food, and the currency flows back to city centers. This advantage of the market-based CIC approach arises because of a feature in its functioning akin to the 'money multiplier' in standard banking systems with fractional reserve requirements studied in economics and operating in the real world. Previous research has indicated that an increase in the value of a national currency does not necessarily reflect to a large extent an increase in the actual productive capacity of a nation [Ryan-Collins, 2011]. Estimates from *Grassroots Economics* imply that a roughly 20x leverage on donated funds into CIC reserves is possible as a result of the creation of CIC at a 4x1 basis and its circulation throughout the local economy prior to its optional redemption into Kenyan Shilling [Ruddick, 2020].

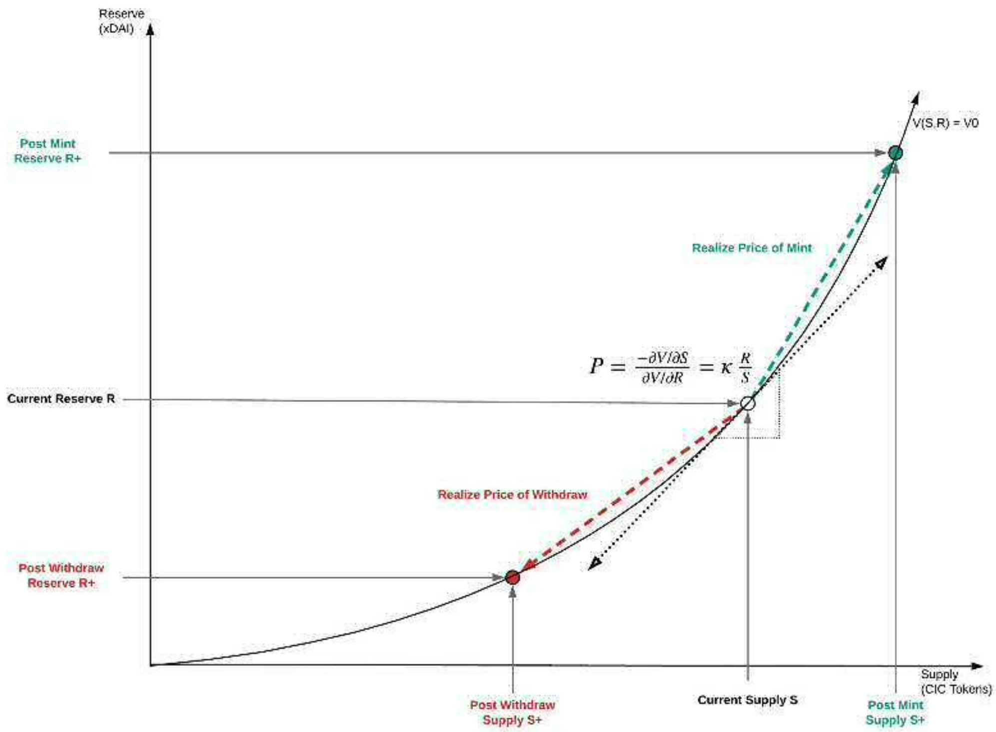

Figure 1. Bonding Curve Illustration of CIC Bancor Implementation

III. Formalized Model

The model we propose in this paper for studying community inclusion currencies within a complex system approach is visually described in Figure 2. The model used here is generalized, which contributes to the build-up of a framework for developing analogous currency simulations in further related research. We will 'layer' (i.e., decompose and describe our model into components and interactions at various levels, or 'layers') in the specific case of *Grassroots Economics* in our simulation construction, as illustrated in Figure 5. The blue box (or block in the diagram) shows the mixing process of subpopulations interacting with each other (i.e., the continuous random matching of pairs of agents, in our specific case, groups of agents, typically studied in economics, in particular in 'search' theory and simulations), and their interactions with the external economy, symbolized by the orange cloud, and with the pink box, or the currency operator. The pink box is the meso-level local economic operator, which is created as an institute in the support of the healthy economic growth of the local economy (the blue box). The pink box economy regulator (or policymaker, in macroeconomic terms) supports the health of the blue box economy by allocations to individual

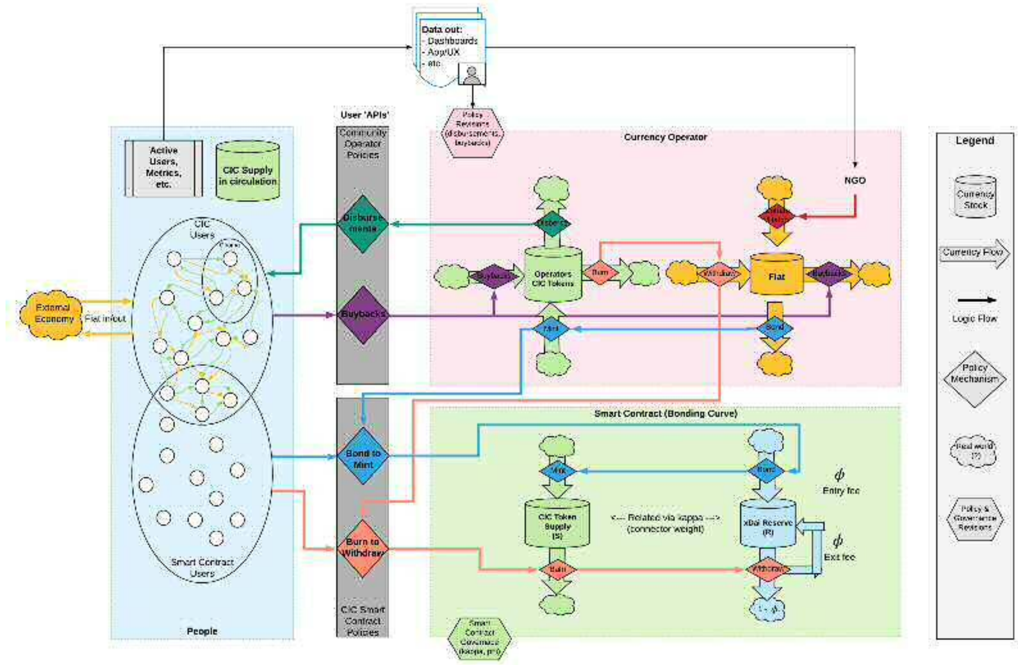

Figure 2. General Model

agents and subpopulations when they join the economy, and provides them the mechanisms of converting allocations, as well as governance policies. The green box is an 'algorithmic monetary policy' rooted in an underlying bonding curve [Zargham et al., 2019], which is analogous to the functioning of a currency board for a national economy, as was noted. The green box is a regulator (or instrument, here a rule-based automatic mechanism) of the pink box (or policymaker), which is offering (or, rather, implementing) policies in the blue box. The goal of our simulations and modeling is to help guide the currency operator symbolized by the pink box in managing (on 'auto-pilot') the green box mechanism to keep the local economy symbolized by the blue box healthy, and promote (regional) economic growth. All parts of the ecosystem (i.e., the model 'environment', as is the customary term in economic theory) must be working in harmony to create homeostasis (i.e., some notion of 'equilibrium', dynamic or evolutionary, that leads to long-run stability or sustainability) in the system and a means for easing the liquidity constraints prevalent in 'failed' local economies. We describe each of these model blocks, or key components, more thoroughly in the subsequent subsections.

A. Mixing Process

The community mixing model, as shown in the blue box in Figures 2 and 5, is a topological object representation of the interactions of subpopulations in a local economy. By modeling the trends and interactions of subpopulations clusters in an economy we can observe system metrics from a macro level to help drive policy decision and economic interventions.

To represent the stochastic process that connects the 'implementation economy' to the 'wider economy', we describe our mixing process of intra and inter subpopulations interacting into a networked, graph model evolving over time. Assume we have a directed graph $\mathcal{G}(\mathcal{V}, \mathcal{E})$ with subpopulations as vertices, or nodes, $\mathcal{V} = \{1...\mathcal{V}\}$ and edges as $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$. 'demand', 'utility', and 'spend' are edges connecting the subpopulations, with 'demand' used to denote desired flow between agents, as $i, j \in \mathcal{E}$. Technically, the graph is a weighted, directed multigraph with more than one edge, $i \longrightarrow j$ for any pair of vertices $i, j \in \mathcal{V}$ with $w_{i,j}$. We chose this meso structure because microeconomic models and simulations, such as agent based modeling, are too detailed (or 'atomistic') for a useful representation of the system level dynamics, whereas a traditional macro equilibrium model, or system dynamics model, is too general for an accurate representation of the economic mixing process [Voshmgir and Zargham, 2019, Dopfer et al., 2004].[11] ABMs are interpretable, providing granularity of agents' behavior. However, ABMs, depending on the use case, can be computationally intractable for realistic configurations. Due to the computational intractability, and complexity of producing realistic, representative agents, for this use case, meso layer modeling was selected instead as it provided enough detail of the economic complexity while reducing computational overhead. Meso layers focus on change, whereas traditional micro and macro models focus on equilibrium and do not as readily account for the evolution and acceptance of rule changes [Dopfer et al., 2004].

Node Types. —

- **Agent** is a user of the system. In the case of our applied simulation, agents are subpopulation representations of the real system data.
- **Cloud** is a representation of the open boundary to the world external to the model.
- **Contract** is the smart contract of the bonding curve.

[11] Agent-based modeling (ABM) is a well-known paradigm to simulate the interaction of autonomous agents and their results on the underlying system [Bonabeau, 2002, Turrell, 2016].

Edges between Agents. — The edge weight $\mathcal{G}_{i,j} > 0$ takes on non-binary values, representing the intensity of the interaction, so we refer to (N, g) as a weighted graph. $\mathcal{E}$ is the set of directed edges, i.e., $i, j \in \mathcal{E}$

- **Demand** is the amount a subpopulation wants to interact in a given timestep (i.e., time period, as most common usage in economics).
- **Fraction of demand in community currency** is the amount in a given transaction the subpopulation wants to interact in token, with 50% of the transaction being in community currency and the remaining 50% of in the native currency, in this case, the Kenyan Shilling.
- **Utility** is the subpopulation's utility (in economic sense) for the transaction. For the 'spend' calculations described later, we stack ranking the utilities to determine, given a liquidity constraint, which subpopulations will interact. We describe the utility types and the ranking mechanism in section III.A.
- **Spend** records the amount of community currency and shilling that was exchanged in a given timestep.
- **Fraction of actual spend in community currency** records the percentage of the transaction that was in community currency, for example, with 50% being in community currency and 50% of the transaction being in the native currency, in this case, shilling.

Subpopulation Modeling. — As described in section III.A, our desire to model at the meso layer has driven the decision to use subpopulation modeling to model the blue box, or mixing process [Dopfer et al., 2004]. To use a subpopulation approach, we are taking a graph zoom operation, bundling agents together based on their 'likeness'. Nodes are constant, with edges being transitive. The algorithm we use for this graph zoom operation is Kmeans Clustering [Lloyd, 1982].

To compute the clusters, we take the *Grassroots Economics* CIC implementation full population of actual USD transactional data from January 1 through May 11, 2020 in xDai data. The data has the following features:

- Payer individual location
- Payer individual business type
- Receiver individual location
- Receiver individual business type
- Weight, which is tokens, exchange amount
- Payer individual CIC wallet balance

- Receiver individual CIC wallet balance

Based on our descriptive statistical analysis and use of the Gap Statistic [Tibshirani et al., 2001], we determined that ('optimally') 50 clusters are representative of the subpopulations, see Figure 3. 50 clusters was decided as our upper bound due to computational limits and the desire to model on a subpopulation vs agent based level. All of the flows inside of the bundle become part of the self-loop flow. For example, within cluster 1, agent A can conclude transactions with agent B: this will not be reflected within our model, as this is intra (not inter) cluster interactions.

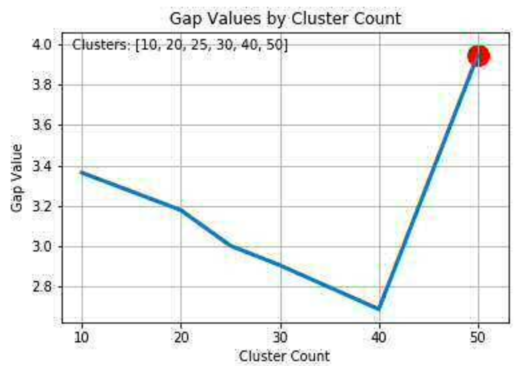

FIGURE 3. GAP STATISTIC OF TESTED CLUSTERS OF AGENTS TO SUBPOPULATIONS.

We calculated the starting native currency of the subpopulations from the 1st to 3rd quartile of cluster source balances. Starting tokens is the clusters median source balance.

Utility types are ordered, and probability of occurrence is calculated, per cluster, based on the real transactional data in our sample. Types and probability for cluster 2 can be seen below in figure 4:

Starting from these subpopulation calculations, we can drive the blue box mixing process rooted in actual data that was computed from agent level interactions brought up to subpopulation level.

B. *Currency Operator*

The pink box, as described above in section III.A, is the meso-level economic operator whose purpose is to promote a healthy economy in the blue box. The currency operator, in this case, *Grassroots Economics*, issues CIC to new users, with the current rule of 400 CIC per each new agent [Ruddick, 2020], provides a mechanism for conversion at 1:1 into Kenyan Shilling, as well as drives monetary policy and structure. In a general form, there is a net outflow to the system caused

* Utility Types Ordered
  * Savings Group
  * Farming/Labor
  * Food/Water
* Utility Types Probability
  * 0.64
  * 0.25
  * 0.11

FIGURE 4. UTILITY TYPES AND THEIR PROBABILITY

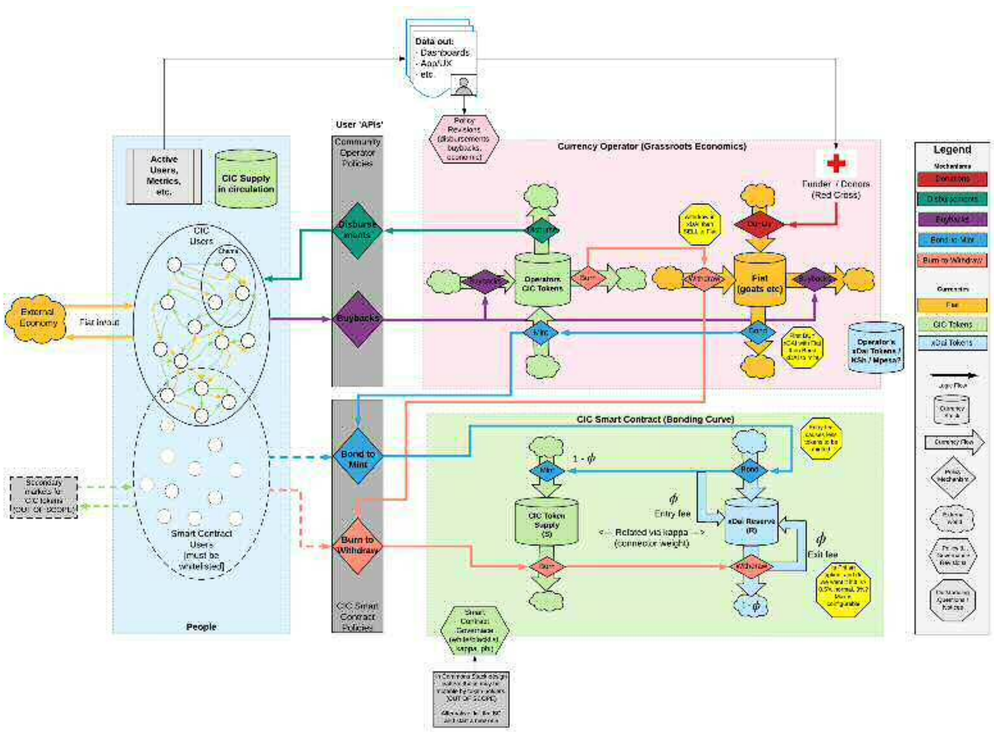

FIGURE 5. SYSTEM DYNAMICS MODEL OF CIC SYSTEM REPRESENTATION.

by the currency operator giving CICs to agents, and allowing the redemption of their tokens. This causes a classic inventory control problem of managing that enough CIC (i.e., token money) and fiat (i.e., fiat money) exists to manage the currency operator's transactions and provide the outflow of liquidity into the system. There are several mechanisms to manage net outflow, such as external donor drip, which is the current process, and illustrated in Figure 5, as well as the introduction of transaction fees. Below we will describe both these mechanisms for the inventory control problem that is embedded into our simulation model, as well as the disbursement and buyback policies.

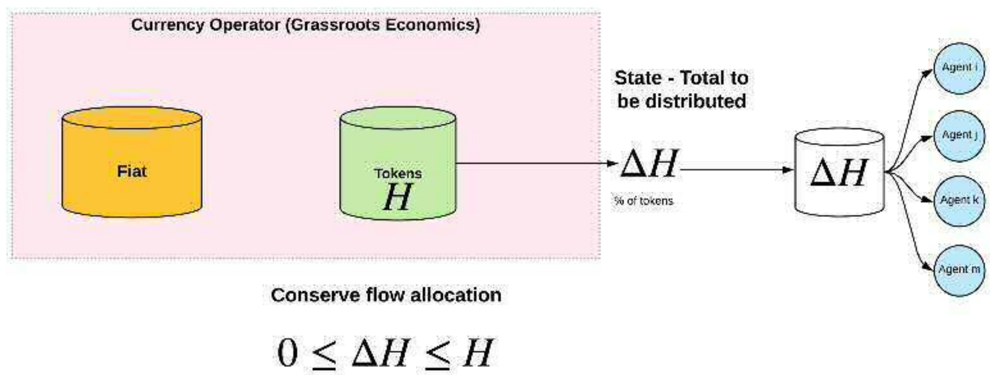

FIGURE 6. SUBPOPULATION CIC DISBURSEMENT

The *inventory_controller* policy addresses the inventory control problem of the system. There is a natural tension between the operator CIC balance and the operator fiat balance as the system has a natural net outflow. Conceptually, we can think of this as a heuristic monetary policy conservation allocation between fiat and CIC reserves. We have created an inventory control function to test if the current balance is an acceptable tolerance. For the calculation, we use the following 2 variables: current CIC balance and current fiat balance; along with 2 parameters: desired CIC and variance – see Figure 7 for the allocation policy. For our model's purposes, we assume that the *Grassroots Economics* operator begins with 100,000 of fiat and CIC, in our simulation initialization.

If the controller wants to mint, the amount decided from the inventory controller, ΔR is inserted into the minting equation, as described above in more detail in the bonding curve section III.C.

There is a built-in process lag of 15 days before the newly 'minted' or 'burned' CIC is added to the respective operator accounts. This lag is a result of the financial lag time of bonding/minting funds and clearing this funds through the traditional banking system. The result of the *inventory_controller* behavior policy are directives to mechanisms to update the system variables according to whether any minting or burning occurred. For disbursement, we assume that every subpopulation has already started off with their CICs, and we assume distribution of a total of 1,000 to each subpopulation every 30 days. There is also a potential for allocation to occur based on a measure of individual agent centrality.

```
if idealFiat - varianceFiat <= actualFiat <= idealFiat
    + (2*varianceFiat):
    decision = 'none'
    amount = 0

    else:
        if (idealFiat - varianceFiat) > actualFiat:
            decision = 'burn'
            amount = (idealFiat + varianceFiat) -
                actualFiat
        else:
            pass
        if actualFiat > (idealFiat + varianceFiat):
            decision = 'mint'
            amount = actualFiat - (idealFiat +
                varianceFiat)
        else:
            pass

    if decision == 'mint':
        if actualCIC < (idealCIC - varianceCIC):
            if amount > actualCIC:
                decision = 'none'
                amount = 0
            else:
                pass
    if decision == 'none':
        if actualCIC < (idealCIC - varianceCIC):
            decision = 'mint'
            amount = (idealCIC-varianceCIC)
        else:
            pass
```

Figure 7. Pseudo code representation of the heuristic inventory control algorithm

C. Currency Regulator - Bonding Curve

A bonding curve is an automatic mechanism of market making and liquidity provision in token economies, analogous to a currency board in national economies [Zargham et al., 2019]. We briefly describe how the CIC bonding curve works, displaying the high level mathematical representations, but detailed explanation of the underlying mathematics and protocol can be found from co-author Michael

Zargham's previous work [Zargham et al., 2019, 2020] as well as from the Bancor protocol [Hertzog et al., 2018. accessed June 14, 2020].

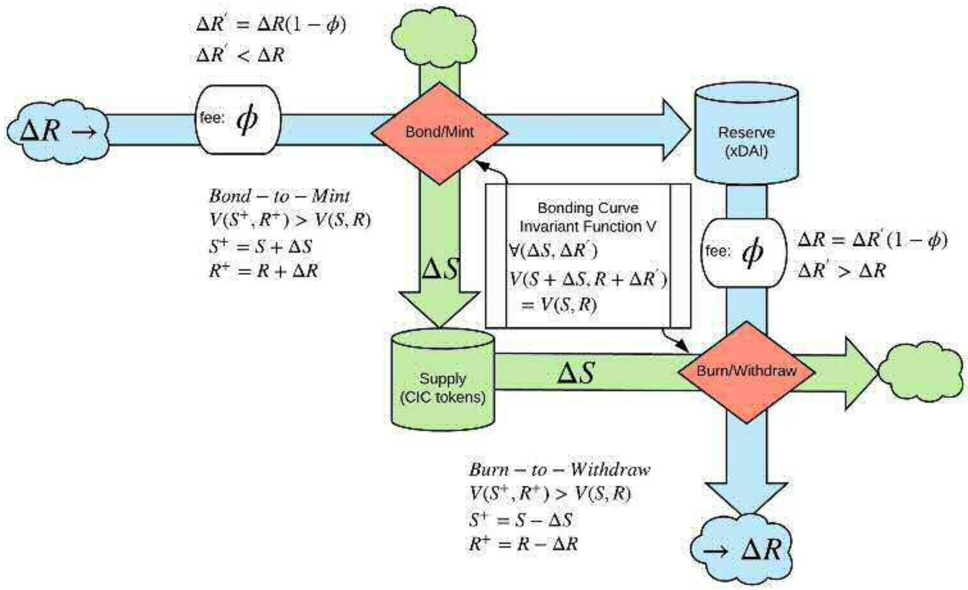

FIGURE 8. CIC BONDING CURVE STOCK AND FLOW DIAGRAM.

An important component of a bonding curve is its conservation function, a measure of a property that is an invariant, which means that the value of the conservation function remains unchanged under the allowable system transitions. For our model, the conservation function is:

$$V(S,R) = \frac{S^\kappa}{R}$$

with R being the xDai in Reserve and S as the Total Supply of CIC tokens in the system.

The deposit to mint equations are deposit ΔR xDAI to mint ΔS CIC tokens

$$\Delta S = mint\big(\Delta R; (R,S)\big) = S\big(\sqrt[\kappa]{(1+\frac{\Delta R}{R})} - 1\big)$$

The burn to withdraw equations are burn ΔS CIC tokens to withdraw ΔR xDAI

$$\Delta R = withdraw\big(\Delta S; (R,S)\big) = R\big(1 - (1 - \frac{\Delta S}{S})^\kappa\big)$$

System level initialization parameters shown below were derived based on simulation, analytical methods, and discussions with the *Grassroots Economics* team.

- $R_0 = 40,000$ xDAI to generate S_0 initial supply
- The 'Connector Weight' in Bancor terms maps to the concept 'Target Reserve Ratio' $\rho = \frac{1}{\kappa} = \frac{R}{P \cdot S}$
- Conversion rate between USD and Kenyan Shilling is approximately 1:100
- Assume $P_0 = 1/100$ in order to ensure spot price is the right order of magnitude
- Leveraged applied to the bonding curve $\kappa = 4$ above implies $S_0 = 4 \times 100 \times 40000 = 16\,Million$ for the initial supply of CIC tokens

Figure 9 shows the base bonding curve case as determined by the originally suggested values by *Grassroots Economics*.

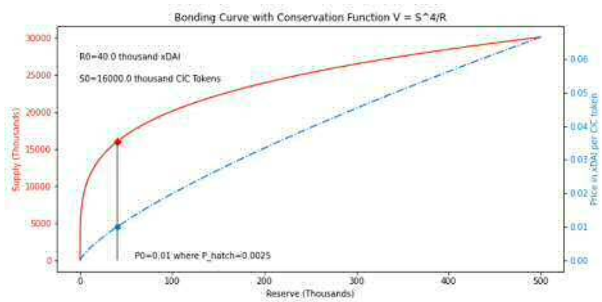

FIGURE 9. CIC bonding curve with initialization values

The bonding curve mathematics are relatively new but not novel in this project, with widespread deployment not prevalent. In the developmental economic context, the success of the *Grassroots Economics* project could be the first deployment of a bonding curve outside a pure token economy implementation. In traditional economics, bonding curves can be viewed as similar to currency boards.

IV. System Walkthrough

A. *Layers in the cadCAD Simulation*

In the cadCAD simulation methodology, we operate on four layers: **Behavior Policies, Mechanisms, States, and Metrics**. We can describe the interaction of these four layers through a differential specification using system modeling syntax [Zargham, 2019]. Information flows do not have explicit feedback loop unless

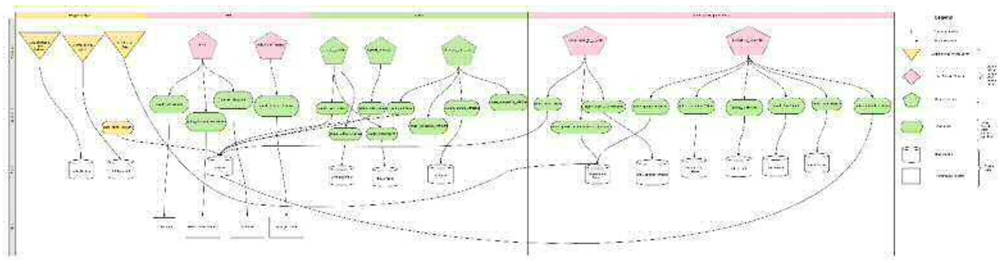

Figure 10. Differential specification of the system.

noted: see Figure 10. **Policies** determine the inputs into the system dynamics, and can come from user input (e.g., instrument variables in macro-modeling), observations from the exogenous environment, or algorithms. **Mechanisms** are functions that take the policy decisions and update the states to reflect the policy level changes. **States** are variables that represent the system quantities (conventionally, stock or state variables in dynamic economic theory and simulation) at the given point in time, and **Metrics** are computed from state variables to assess the health of the system (i.e., they resemble certain policy criteria or guiding measurements in economics). Metrics can often be thought of as KPIs, or Key Performance Indicators. See Figure 11 for a snippet of the partial state update blocks and Table 2 for a listing of the states of the system.

```
partial_state_update_block = {
    # Users
    'Behaviors': {
        'policies': {
            'action': choose_agents
        },
        'variables': {
        'network': update_agent_activity,
        'outboundAgents': update_outboundAgents,
        'inboundAgents':update_inboundAgents
        }
    },
```

Figure 11. Example Partial State Update Blocks

B. Order of Events

In our systems – see Figure 10 – differential specification, we have 4 separate parts of the model, *Exogenous signals, KPI, System, and Currency Development Entity*. Each part is comprised of 1 or more partial state update blocks, which when taken in sequence, create state update, or one increment of a timestep. **Exogenous** signals are a substep of the system with mechanisms that do not have policies. **System** is the Figure 5 blue box, or mixing process interactions. **Currency Development Entity** is the policies and mechanisms for the currency operator, or the Figure 5 pink and green boxes, whereas **KPI** are the system metrics. Below we enumerate the substeps of a system timestep.

1) Calculate the starting balance of the individual subpopulations every 30 days, the subpopulations actual 30 day spend, as well the periodic donor shilling drip[12], and clearing out the previous simulation step network mixing process activity. The starting balances and 30 day spend mechanisms are used to create variables that serve as a basis to simulate the 'aggregated agent' withdrawal based on the *Grassroots Economics* CIC withdraw policy.

2) The System is our graph mixing process. Individual subpopulations will interact with each other to simulation inter-subpopulation value flows. With the graph structure discussed in section III.A, the first behavior, *choose_agents*, takes a uniform random sample of 46 from the 51 subpopulations (50 clusters plus the external economy) for the payer subpopulations and another uniform random sample for the receiver subpopulations. The behavior policy then calculates the payer demands based on a Gaussian distribution computed from the μ actual CIC transactions involving the subpopulation and the σ of the actual transactions, as described in section III.A. If the payer is the external economy node, we compute a Gaussian distribution based on the average of the average subpopulation μ and σ. To calculate the payer subpopulation's utility, we take a uniform distribution of the source subpopulations business types and use their probability of occurrence, i.e. Food and Water type occurs 41% of the time in subpopulation 1 inter-cluster interactions, so we will choose this utility type 41% of the time. Note that for the scope of our simulations, we are assuming each subpopulation interacts once with one utility type for each timestep. As the result of this behavior policy, we update the mixing graph with the edges that are interacting, their demand, utility, and the fraction of demand in CIC. For simulation purposes, we are assuming that the fraction of demand for a transaction is 50% fiat, 50% CIC, where 100% fiat if the subpopulation is interacting with the external environment.

[12]The basic model features an issuer with goods or services on offer (such as goats). The donor side was only bootstrapping, and future donations will go into the bonding curve.

3) The second behavior of the system, *spend_allocation*, is calculated based on the desired interacting subpopulation's demand, utility, and liquidity constraints, i.e., the amount of CIC and shilling each subpopulation has available. We iterate through the desired demand and allocate based on a stack ranking of utility $v_{i,j}$ over demand $\frac{v_{i,j}}{d_{i,j}}$ until all demand for each subpopulation is met or subpopulation i runs out of CIC and shilling. In the mechanisms, we then update the graph with the actual spend between agents.

4) The third and final behavior in the Systems section is the *withdraw_calculation*. Per *Grassroots Economics* policy [Ruddick, 2020], individual users are able to withdraw up to 50% of their CIC balance if they have spent 50% of their balance within the last 30 days at a conversion ratio of 1:1, meaning that for every one token withdraw, they receive 1 in shilling. For our subpopulation model, we are assuming that the agents want to withdraw as much as they can. One generalization we make from the system is that agent will have their '30-day clocks' starting when they have joined the system. For simplification, in our model, we are assuming that each subpopulation is on the same 30-day time clock. This produces jagged withdrawal graphs, but the net flows of the system are the same. This is one of the most important control points for the *Grassroots Economics* CIC operator. The more people withdraw CIC from the system, the more difficult it is on the system. The more people can withdraw, the better the adoption, however. The inverse also holds true: the fewer individuals can withdraw, the lower the adoption. 30,000 is the max allowable amount to be withdrawn per 30 days. The mechanisms based on the behavior policy update, the operator fiat and CIC balances, the aggregated withdraw state, as well as the individual subpopulations, are based on their observed activity.

5) The next sequence in our partial state update blocks is the Currency Development Entity. This sequence has two behaviors, *disbursement_to_agents* and *inventory_controller*, as described above in section III.B. In *disbursement_to_agents*, CIC is distributed to the subpopulations as a means of Universal Basic Income, or UBI.

6) The final section of our system model is the KPI's partial state update blocks. This policy group has two behaviors, *kpis* and *velocity_of_money.* The *kpis* behavior policy iterates through the network model edges to ascertain the subpopulation edge weights of demand and spend for the current timestep. The policy function aggregates the spend and demand for a system level view of how much spend and demand occurred on the network during the timestep as well as spend over demand, to see how much of the demand was fulfilled. A spend over demand of 1 means that not all demand was satisfied whereas a value of 1 denotes that all subpopulation wants were met. The behavior policy has three subsequent mechanisms that update the

metrics variables of KPIDemand, KPISpend, and KPISpendOverDemand with the timesteps results.

- Behavior policy *velocity_of_money* calculates the velocity of money per timestep via indirect measurement. Research by De la Rosa and Stodder has shown that the velocity of local currencies can be as much as five times higher than their corresponding national currencies(**?**).

$$V_t = \frac{PT}{M}$$

  where V_t is the velocity of money for all agent transactions in the time period examined, P is the average price level, T is the aggregated real value of all agent transactions in the time period examined, and M is the average money supply in the economy in the time period examined. The *velocity_of_money* mechanism updates the metric variable of VelocityOfMoney.

V. System Run and Results – Outline with Graphical Sketch

cadCAD provides the ability for Monte Carlo runs that reflect the description of our model and algorithm thus far. Due to the stochastic nature of our system, Monte Carlo runs will provide a more accurate readout on how a system will perform. As a result of the size and complexity of the model with the subpopulations, we ran 5 Monte Carlo runs over 100 timesteps to produce time series quartile charts of Subpopulation Spend, KPISpendOverDemand, VelocityOfMoney, and operator CIC and fiat balances. As a result of the simulations [Clark, 2020] – see figures 12, 13, 14, 16, and 15 – we can observe the predicted net outflow of fiat from the system, or enable some sort of fee structure. For the sake of this illustration, and a desire for this sort of simulation model to not be completely 'driverless', the rough heuristic inventory control algorithmic policy defined above was turned off for the simulations run.

As has been illustrated in this paper, the potential for system level decision-making regarding the withdrawal policies, liquidity requirements of the currency development operator, the introduction of transaction fees, the ability of traders and investors to interact with the network to provide liquidity with the bonding curve, and calculating the fiscal multiplier of an external liquidity development investment are all examples of subsequent work. It could be performed for a specific currency development use case, consistent with the network-based framework we presented above.

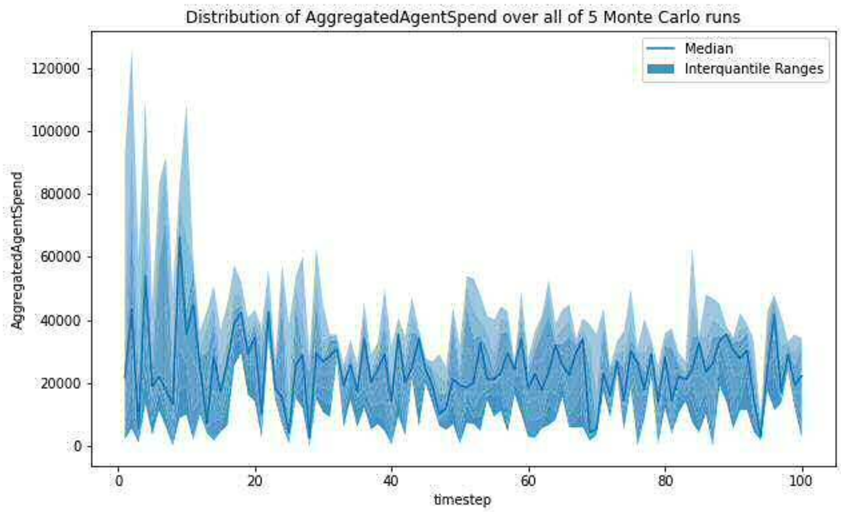

FIGURE 12. AGGREGATED INTER-SUBPOPULATION SPEND. THIS FIGURE SHOWS THE AGGREGATED INTER-SUBPOPULATION SPEND PER TIMESTEP OF THE SIMULATION. AFTER THE SYSTEM INITIALIZATION OF AGENT SPEND AND ECONOMY OUTFLOWS, THE SPEND STAYS RELATIVELY CONSTANT, DESPITE NO NEW AGENTS INTRODUCED.

VI. Concluding Remarks

In this paper, we have examined what community inclusion currencies are, based on the simulation application we performed with regard to the *Grassroots Economics* CIC project in Kenya. Furthermore, we created a network-based complex systems model of subpopulation interactions, and a simulation of the performance of the economic system given some hyperparameters.

We attempted to bridge complex systems modeling and simulation approaches and the corresponding terminology, typical for computer science and systems engineering, with concepts, theories and interpretations that are well grounded in economic analysis and monetary theory. In doing so, our aim was to highlight the potential usefulness of the emerging blockchain-technology backed community inclusion currencies now popular in cryptoeconomics. Essentially, we see the potential of such CICs mostly as a local and temporary liquidity-provision institutional device in local economies to increase their internal exchange and economic value added, thereby serving as a market-based mechanism to alleviate poverty, akin in its automatism and credibility to a currency board in national economies. Yet, we do not view such CIC systems as a long-run solution to the problems of liquidity shortage that decreases internal trade, isolates these backward regions from the rest of the country and the world, and depresses their

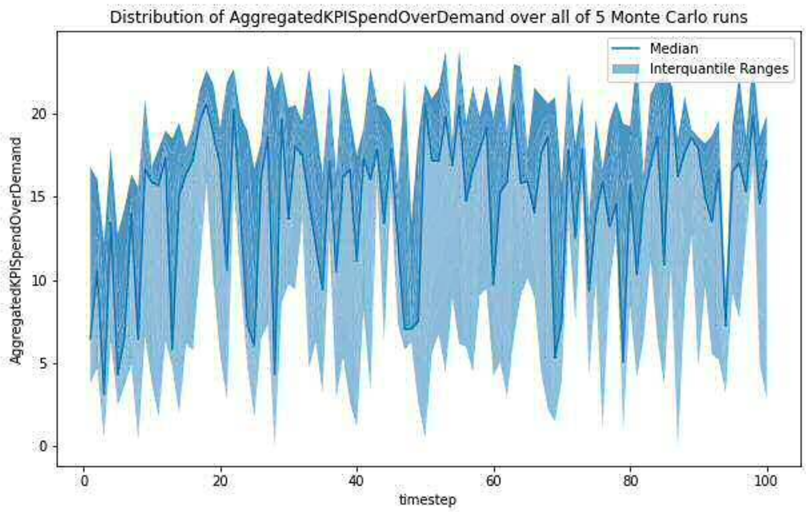

Figure 13. Aggregated inter-subpopulation KPI spend over demand. A value of 1 means that all demand is fulfilled, while a value of less than 1 shows us that not all subpopulation wants were met, based off of our stochastic demand function.

growth, employment and prosperity. The ultimate goal of these CIC systems is rather to promote a transition toward complete inclusion and integration into the national and global economies, pulling over the communities and regions out of self-sufficiency and poverty into more advanced stages of economic development and well-being.

A. Main Findings and Contributions

Our contribution to the economic literature, in particular on new forms of money and cryptoeconomics, is three-fold:

- first, in taking a novel meso-economic approach, in-between the standard extremes of micro and macro, in modeling the local economy and its use of a CIC.
- second, our model allows us to elicit utility from actual transactions and to divide accordingly the individuals in a community into typical subgroups, representing inferred spending-behavior heterogeneity in the society across consumer types, based on observed and recorded CIC transactions.
- third, we further relate our findings based on the *Grassroots Economics* initiative to comparative analysis of some key economic benefits and costs

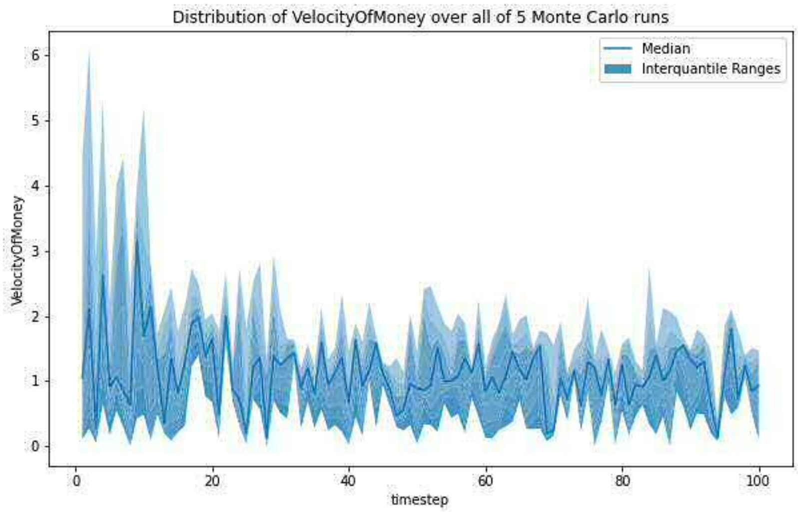

Figure 14. Aggregated inter-subpopulation velocity of money. Very similar to trend and insight from figure 12

of community inclusion currencies and their mechanism of implementation vs those of a currency board or a central bank in conducting monetary policy in the conventional way.

The contribution of this paper to the computer science, and tokeneconomics communities are three-fold as well:

- in providing a scaffold for modeling community currency viability and net flows.
- in implementing a network-based dynamical systems modeling approach that is more grounded in economic and monetary theory, to simulate a subpopulation mixing processes.
- finally, in applying computational modeling of complex systems embodying key economic principles.

By utilizing complex systems modeling and modern computational simulations, modeling of economic systems can be accomplished to aid development efforts and guide monetary policy decisions.

B. Future Research

In this paper, we have developed a meso-level subpopulation model for modeling the *Grassroots Economics* CIC project. This framework, however, can be

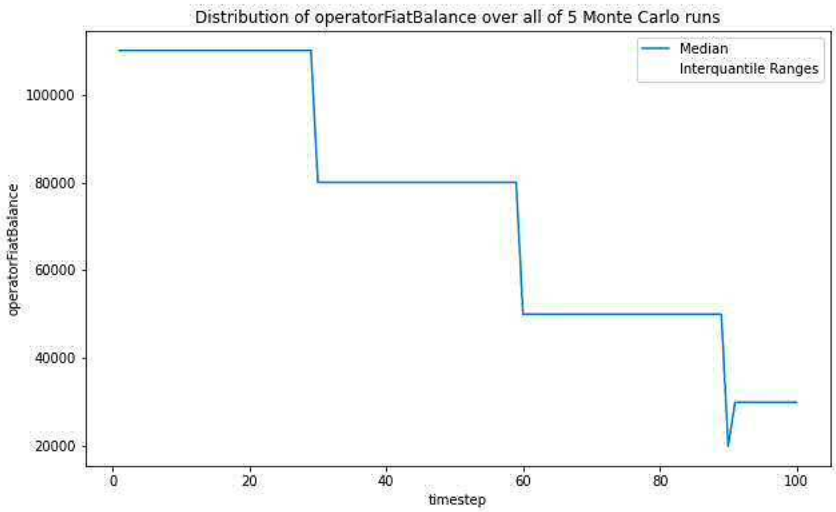

FIGURE 15. OPERATOR FIAT BALANCE. SINCE THE CIC SYSTEM IN THIS SIMULATION IS NET OUTFLOW, RELYING ON DONATIONS, THE BALANCE IS DOWNWARD TRENDING, PER EXPECTATION. THE SUBSEQUENT INTRODUCTION OF FEES, SEE SECTION VI.B, WILL BE FOCUSED ON MAKING THIS BALANCE STATIC OR TRENDING SLIGHTLY POSITIVE.

configured for other economic modeling use cases. Our model was designed to be leveraged for making decision about how to govern a local economy and manage its liquidity and non-barter exchange.

Future research along these lines includes adding more detailed adoption processes, the introduction of fees, and the execution of simulation experiments to drive operational decision making. Enumerated below are the recommended modeling next steps:

- User adoption and randomized withdrawal
  - Poisson distribution – fractions of CIC in subpopulations (change withdrawal and distribution policies)
    - Randomize when subpopulations withdraw. They each have a separate '30-day clock'.
    - Cash-outs are discrete events in continuous time. Time between events is a flow-weighted exponential distribution. Generate time between events, with the amount to disburse based on the mixing process.
    - Lower bound is 30 days. There is a max of 30k withdrawal per 30 days for the system. Some cash out at every time step.

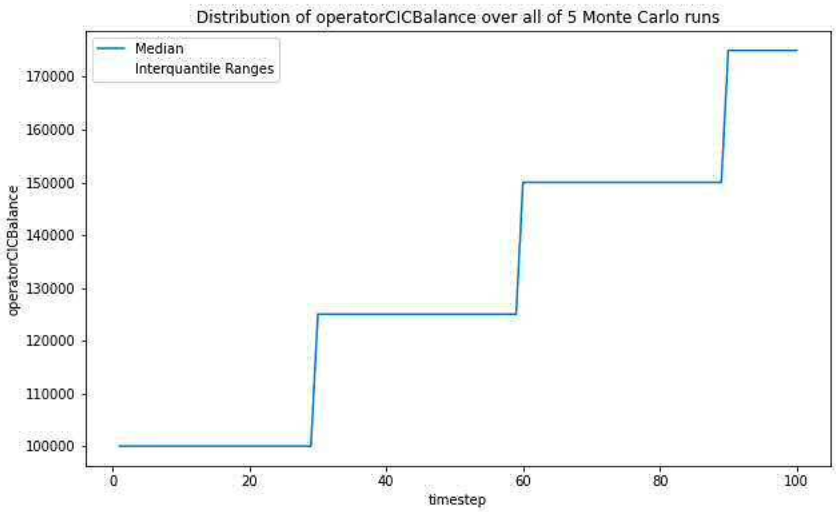

FIGURE 16. OPERATOR CIC BALANCE. AS A RESULT OF MINTING AND BUYBACKS, THE CIC BALANCE IS INCREASING, AS EXPECTED.

    * Poisson distribution for each subpopulation for new arrivals.
    * For each subpopulation, we will represent these arrivals by the percentage of CIC that is available for withdrawal.

- Weighted edges for choosing probability of subpopulations interacting; i.e., subpopulations interact with the same 5 subpopulations primarily.
- Fee mechanisms.
  - Parameter sweeps on fee percentages, and which actors to impose them, i.e., traders, investors, or general users via transaction fees.
- Payer and receiver needs to have separate amount of CIC demanded. Payer wants to pay in 100% fiat, whereas receiver may only want 5% fiat. Need to reconcile the two and track the difference.
  - Create 'negotiator' policy and separate generator functions.
  - Fraction of demand in CIC edge type to dictionary of type payer key value and receiver key value.
- Move to closed loop model without external drips or new buy-ins, meaning, removing external liquidity infusions, can the economy function by itself, and what fees are required for the Currency Operator to not run out of either fiat or CIC.

- Advanced algorithmic inventory allocation.
  - If scarcity on both sides, add feedback to reduce percentage able to withdraw, frequency one can redeem, or redeem at less than par.
- Percentage of k cycles centrality – for rewards feedback/basic income.

C. Reproducibility

In order to replicate the simulation results we presented here, we direct the reader to visit `https://www.anaconda.com/products/individual` in order to download Python 3.7+ for the specific version of operating system, i.e., Linux, Mac OS. To install cadCAD and download the source code, we direct the reader to run the commands shown in figure 17 in their command line:

```bash
# Install cadCAD
pip install cadCAD==0.3.1

# Download code
git clone -b paper https://github.com/BlockScience/\
Community_Inclusion_Currencies.git

# Access the repository
cd Community_Inclusion_Currencies

# Run a notebook server
jupyter notebook
```

FIGURE 17. Bash shell commands to download simulation code

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Appendix

A1. CIC Mathematical Specification

Assume we have a weighted, directed multigraph $\mathcal{G}(\mathcal{V}, \mathcal{E})$ with subpopulations as vertices, or nodes, $\mathcal{V} = \{1...\mathcal{V}\}$ and edges as $\mathcal{E} \subseteq \mathcal{V} \times \mathcal{V}$. ‘Demand’, ‘utility’, and ‘spend’ are edges connecting the subpopulations, with ‘demand’ used to denote desired flow between subpopulation agents, as $i, j \in \mathcal{E}$.

A2. Node Types

Node types, $\mathcal{V}$, can take on the 3 types, *Agent, Cloud, or Contract*, and are enumerated below.

- **Agent** is a subpopulation of the system. Agents are subpopulation representations of the real system data and are represented by $\mathcal{V}_{A^n}$. Agents are unique subpopulations and stay constant throughout the simulation.
- **Cloud** is a representation of the open boundary to the external world; is unique, and is represented by $\mathcal{V}_{Cloud}$.
- **Contract** is the smart contract of the bonding curve; does not need to be unique, and is represented by $\mathcal{V}_{Contract}$.

A3. Edges between Agents

The edge weight $\mathcal{G}_{i,j} \geq 0$ takes on non-binary values, representing the intensity of the interaction. $\mathcal{E}$ is the set of directed edges, i.e., $i, j \in \mathcal{E}$

- **Demand** is the amount a subpopulation wants to interact in a given time step (i.e., period, as most common usage in economics), represented by $\mathcal{E}_{D_{i,j}}$.
- **Fraction of demand in community currency** is the amount in a given transaction, the subpopulation wants to interact in token, with 50% of the transaction being in community currency and the remaining 50% of in the native currency. It is represented by $\mathcal{E}_{F^D_{i,j}}$.
- **Utility** is the subpopulation’s utility (in economic sense) for the transaction. For the ‘spend’ calculations described later, we stack ranking the utilities to determine, given a liquidity constraint, which subpopulations will interact. It is represented by $\mathcal{E}_{U_{i,j}}$.
- **Spend** records the amount of community currency and shilling that was exchanged in a given time step. It is represented by $\mathcal{E}_{S_{i,j}}$.

- **Fraction of actual spend in community currency** records the percentage of the transaction that was in community currency, for example, with 50% being in community currency and 50% of the transaction being in the native currency, in this case, shilling. It is represented by $\mathcal{E}_{F^S_{i,j}}$.

At an intermediate step of the system, a node, such as subpopulation agent 10 $\mathcal{V}_{A^1 0}$ interacts with agent 12 $\mathcal{V}_{A^1 2}$, will have an edge weight at all edges types, such as $\mathcal{E}_{D_{10,12}} = 300$, $\mathcal{E}_{F^D_{10,12}} = 50\%$, $\mathcal{E}_{U_{10,12}} = Food/Water$, $\mathcal{E}_{S_{10,12}} = 200$, $\mathcal{E}_{F^S_{10,12}} = 50\%$

A4. State Space

States or objects or points representing the current configuration of the system. $X \in \mathcal{X}$. Each of the states in this simulation are defined below.

DEFINITION 1: ***Network****: A Multi-directed graph notated as* $\mathcal{G}(\mathcal{V}, \mathcal{E})$. *This state contains the multi-graph of nodes and their weighted edges of interaction.*

DEFINITION 2: ***startingBalance****: The starting subpopulation CIC balance, notated as* SB. $SB > 0$ *for all* $\mathcal{V}_{A^n}$.

DEFINITION 3: ***30_day_spend****: Subpopulation spend over the last thirty time steps; notated as* DS. $DS >= 0$ *for all* $\mathcal{V}_{A^n}$.

DEFINITION 4: ***drip****: Amount of currency dripped into network by external parties during a time step; notated as* D. $D >= 0$

DEFINITION 5: ***outboundAgents****: Subpopulation agents that are paying during the time step; notated as* OA. $0A >= 0$

DEFINITION 6: ***inboundAgents****: Subpopulation agents that are receiving during the time step; notated as* IA. $IA >= 0$

DEFINITION 7: ***withdraw****: Subpopulation agent actual withdraw, notated as* W.

DEFINITION 8: ***fundsInProcess****: Funds awaiting settlement; notated as* FIP.

DEFINITION 9: ***totalMinted****: Total amount of CIC minted during the simulation; notated as* M. $M >= 0$

DEFINITION 10: ***totalBurned****: Total amount of CIC burned during the simulation; notated as* B. $B >= 0$

DEFINITION 11: ***operatorFiatBalance****: Currency operator Fiat balance; notated as* OBF. $OBF > 0$

DEFINITION 12: ***operatorCICBalance****: Currency operator CIC balance; notated as* OCB. $OCB > 0$

DEFINITION 13: ***totalDistributedToAgents****: Total amount of CIC distributed to agents during the simulation; notated as* D_A. $D_A > 0$

A5. Metric State Space

DEFINITION 14: ***KPIDemand**: Subpopulation demand from the time step in per subpopulation, notated as KPI_D. $KPI_D > 0$*

DEFINITION 15: ***KPISpend**: Subpopulation spend from the time step per subpopulation, notated as KPI_S. $KPI_S >= 0$*

DEFINITION 16: ***KPISpendOverDemand**: Subpopulation spend divided by demand per subpopulation; notated as $KPI_{\frac{S}{D}}$. $KPI_{\frac{S}{D}} >= 0$*

DEFINITION 17: ***VelocityOfMoney**: Velocity of money from the time step; notated as V_M. $V_M > 0$*

A6. Mechanisms

DEFINITION 18: ***update_agent_activity**: takes in outboundAgents, inboundAgents, stepDemands, and stepUtilities at each time step as determined by the **Choose_agents** action and updates the $\mathcal{G}(\mathcal{V}, \mathcal{E})$ $\mathcal{E}_{D_{i,j}}$,$\mathcal{E}_{F^D_{i,j}}$, and $\mathcal{E}_{U_{i,j}}$ based off of the **Choose_agents** action.*

DEFINITION 19: ***update_outboundAgents**: updates the **outboundAgents**, OA state based on the **Choose_agents** time step bound action.*

DEFINITION 20: ***update_inboundAgents**: updates the **inboundAgents**, IA state based on the **Choose_agents** time step bound action.*

DEFINITION 21: ***update_node_spend**: updates the **network**, $\mathcal{G}(\mathcal{V}, \mathcal{E})$ state based on the **spend_allocation** time step bound action.*

DEFINITION 22: ***update_withdraw**: updates the **withdraw**, W state based on the **withdraw_calculation** time step bound action.*

DEFINITION 23: ***update_network_withdraw**: updates the **network**, $\mathcal{G}(\mathcal{V}, \mathcal{E})$ state based on the **withdraw_calculation** time step bound action.*

DEFINITION 24: ***update_operatorFiatBalance_withdraw**: updates the **operatorFiatBalance**, OBF state based on the **withdraw_calculation** time step bound action.*

DEFINITION 25: ***update_operatorCICBalance_withdraw**: updates the **operatorCICBalance**, OCB state based on the **withdraw_calculation** time step action.*

DEFINITION 26: ***update_agent_tokens**: updates the **network**, $\mathcal{G}(\mathcal{V}, \mathcal{E})$ state based on the **disbursement_to_agents** time step bound action.*

DEFINITION 27: ***update_operator_FromDisbursements****: updates the* ***operatorCICBalance*** *OCB state based on the* ***disbursement_to_agents*** *time step bound action.*

DEFINITION 28: ***update_totalDistributedToAgents****: updates the* ***totalDistributedToAgents****, D_A state based on the* ***disbursement_to_agents*** *time step bound action.*

DEFINITION 29: ***update_operator_fiatBalance****: updates the* ***operatorFiatBalance****, OCF state based on the* ***inventory_controller*** *time step bound action.*

DEFINITION 30: ***update_operator_cicBalance****: updates the* ***operatorCICBalance****, OCB state based on the* ***inventory_controller*** *time step bound action.*

DEFINITION 31: ***update_totalMinted****: updates the* ***totalMinted****, M state based on the* ***inventory_controller*** *time step bound action.*

DEFINITION 32: ***update_totalBurned****: updates the* ***totalBurned****, B state based on the* ***inventory_controller*** *time step bound action.*

DEFINITION 33: ***update_fundsInProcess****: updates the* ***fundsInProcess****, FIP state based on the* ***inventory_controller*** *time step bound action.*

DEFINITION 34: ***update_KPIDemand****: updates the* ***KPIDemand****, KPI_D state based on the* ***kpis*** *time step bound action.*

DEFINITION 35: ***update_KPISpend****: updates the* ***KPISpend****, KPI_S state based on the* ***kpis*** *time step bound action.*

DEFINITION 36: ***update_KPISpendOverDemand****: updates the* ***KPISpendOverDemand****, $KPI_{\frac{S}{D}}$, state based on the* ***kpis*** *time step bound action.*

DEFINITION 37: ***update_velocity_of_money****: updates the* ***VelocityOfMoney****, V_M, state based on the* ***velocity_of_money*** *time step bound action.*

EXOGENOUS PROCESSES. —

DEFINITION 38: ***calculate_drip****: In our version of the simulation, as of May 2020, a periodic donor drift could occur. The logic that we have is that every 90 days, we calculate drift based off an initial amount of $10,000 reduced by $5,000 per 90 days, with a lower bound of 0. The amount calculated here determines the transient state D.*

DEFINITION 39: ***startingBalance****: Calculate agent starting balance every 30 days and store in startingBalance dictionary state, SB.*

DEFINITION 40: ***30_day_spend****: Aggregate agent spend, DS. Refreshed every 30 days.*

A7. Actions

DEFINITION 41: ***Choose_agents*** *is an action that determines which subpopulations, $\mathcal{V}_{A^n}$, will interact during the given time step; and create their respective $\mathcal{G}_{i,j}$ weights.*

Choose_agents takes a uniform random sample of 46 from the 51 subpopulations (50 clusters plus the external economy) for the payer subpopulations and another uniform random sample for the receiver subpopulations. The behavior then calculates the payer demands based on a Gaussian distribution computed from the μ actual CIC transactions involving the subpopulation and the σ of the actual transactions. If the payer is the external economy node, we compute a Gaussian distribution based on average of the average subpopulation μ and σ. To calculate the payer subpopulation's utility, we take a uniform distribution of the source subpopulation's business types and use their probability of occurrence, i.e., Food and Water-type occur 41% of the time in subpopulation 1 inter-cluster interactions, so we will choose this utility type 41% of the time. Note that for the scope of our simulations, we are assuming each subpopulation interacts once with one utility type for each time step. The output of this action is the outboundAgents, inboundAgents, stepDemands, and stepUtilities.

DEFINITION 42: ***spend_allocation*** *is an action that takes the mixing subpopulation agents,$\mathcal{V}_{A^n}$, demand $\mathcal{E}_{D_{i,j}}$, and utilities $\mathcal{E}_{U_{i,j}}$ for a given time step and allocates subpopulation agent shillings and tokens based on utility and scarcity to determine for actual spend $\mathcal{E}_{S_{i,j}}$, and fraction of actual spend in community currency, $\mathcal{E}_{F^S_{i,j}}$.*

spend_allocation, is calculated based on the desired interacting subpopulation's demand, utility, and liquidity constraints, i.e., the amount of CIC and shilling each subpopulation has available. Iterate through the desired demand and allocate based on a stack ranking of utility $v_{i,j}$ over demand $\frac{v_{i,j}}{d_{i,j}}$ until all demand for each subpopulation is met or subpopulation i runs out of CIC and shilling. The action returns a list of the paying subpopulation agents, a list of the receiving subpopulation agents, and the list of the spend amounts.

DEFINITION 43: ***withdraw_calculation*** *is an action that determines the number of shillings agents $\mathcal{V}_{A^n}$ can withdraw over 30 days.*

withdraw_calculation per *Grassroot Economics* policy(**?**) at the time of this simulation, individual users were able to withdraw up to 50% of their CIC balance if they have spent 50% of their balance within the last 30 days at a conversion ratio of 1:1, meaning that for every one token withdraw, they would receive 1 in shilling. For simplification, it is assumed that each subpopulation agent, $\mathcal{V}_{A^n}$, is on the same 30-day clock and withdraws the max amount available(30,000 is the max allowable amount to be withdrawn per 30 days). A dictionary of the agent and their withdrawal amount is returned from this action.

DEFINITION 44: ***disbursement_to_agents*** *is an action that periodically distributes CIC to agents, $\mathcal{V}_{A^n}$. The action returns a boolean for distribute, and a dictionary with the agent as a key and the value as the amount.*

disbursement_to_agents is determined by a parameter, FrequencyOfAllocation, which for the simulations, which was set to 30. The amount is determined by a parameter unadjustedPerAgent, which was set to 100. unadjustedPerAgent was then multiplied by the agent allocation, a dictionary with agent as the key, centrality, and allocation value as the values. For the time being, the centrality and allocation value was set to 1 for all agents. A v2 of this model would gauge this allocation based on agent centrality to the network.

DEFINITION 45: ***inventory_controller*** *is an action that as a monetary policy conservation allocation between the* ***operatorFiatBalance****, OBF and* ***operatorCICBalance****, OBC states.*

inventory_controller is in place to address the inventory control problem of the net outflow system by balancing the OBC and OBF states. The inventory control function tests if the current balances are within an acceptable tolerance. For the calculation, we use the following 2 states: current CIC balance, OBC and current fiat balance, OBF; along with 4 parameters: idealCIC, varianceCIC, idealFiat, and varianceFiat. If the balances are not within the acceptable tolerances, the function would return a decision to either mint or burn CICs, along with the amount to mint or burn. For this model's purposes and the initial simulations, the inventory_controller has been turned off to observe the system's performance under the net outflow condition. The action returns a string of burn, mint, or none; a float of the calculated change in fiat, a float of the calculated change in CIC, and a dictionary of the funds in process, which consists of a time step key, with a follow if the time step + a process lag parameter, currently set to 15 days, appended to a list embedded within the value, along with the decision, cicChange, and fiatChange.

DEFINITION 46: ***kpis*** *is an action that calculates the system KPI's of: KPIDemand, KPISpend, and KPISpendOverDemand*

kpis iterates through the network $\mathcal{G}(\mathcal{V}, \mathcal{E})$ model edges to ascertain the subpopulation edge weights of demand, $\mathcal{E}_{D_{i,j}}$, and spend,$\mathcal{E}_{S_{i,j}}$, for the current time step. The policy function aggregates the spend and demand for a system level view of how much spend and demand occurred on the network during the time step as well as spend over demand, to see how much of the demand was fulfilled. A spend over demand of 1 means that not all demand was satisfied, whereas a value of 1 denotes that all subpopulation wants were met. The action has three subsequent mechanisms returns the dictionaries of KPIDemand, KPISpend, and KPISpendOverDemand with agent,$\mathcal{V}_{A^n}$, as the key and the KPI as the value.

DEFINITION 47: ***velocity_of_money*** *is an action that calculates the velocity of money per timestep via indirect measurement.*

velocity_of_money

$$V_t = \frac{PT}{M}$$

Where V_t is the velocity of money for all agent transactions in the period examined, P is the average price level, T is the aggregated real value of all agent transactions in the time period examined, and M is the average money supply in the economy in the period examined.

cluster	median_source_balance	1st_quartile_source_balance	3rd_quartile_source_balance
0	150.00	56.00	403.96
1	340.00	118.46	506.60
2	250.00	105.00	592.96
3	20.00	64,767.51	64,767.51
4	330.00	251,652.00	251,652.00
5	320.00	124.50	1,501.41
6	240.00	4,139.28	7,214.90
7	300.00	146.10	869.82
8	300.00	1,002.50	1,557.01
9	50.00	17,145.78	18,304.36
10	900.00	52,676.20	55,142.93
11	120.00	100.00	419.96
12	400.00	121,082.43	121,082.43
13	180.00	112.00	816.30
14	300.00	28,849.43	38,653.54
15	6,000.00	27,619.22	37,106.89
16	132.50	66.36	770.65
17	130.00	251,652.00	251,652.00
18	160.00	148.00	838.46
19	5,000.00	38,653.54	38,653.54
20	150.00	67.22	315.00
21	10,000.00	121,082.43	121,082.43
22	200.00	6,429.46	9,074.79
23	10,000.00	555.04	5,726.66
24	200.00	104.48	602.02
25	200.00	96.43	437.96
26	35,000.00	52,676.20	63,234.80
27	20,000.00	251,652.00	251,652.00
28	100.00	64.73	425.00
29	500.00	36,824.50	40,953.15
30	425.00	15,182.03	17,145.78
31	13,320.00	485.94	6,349.27
32	500.00	21,660.89	25,695.83
33	500.00	11,210.00	13,156.46
34	1,000.00	100,579.18	100,579.18
35	390.00	100.46	819.33
36	150.00	2,845.01	4,158.50
37	250.00	3,338.98	5,597.38
38	45,000.00	1,274.91	2,823.81
39	36,300.00	6,724.88	20,030.91
40	960.00	38,653.54	51,710.52
41	120.00	114.50	537.94
42	200.00	68.00	542.92
43	100.00	100.00	415.43
44	220.00	20.93	895.66
45	600.00	14,050.30	18,304.36
46	62,000.00	63,145.96	63,145.96
47	500.00	9,276.23	14,050.30
48	900.00	63,234.80	64,767.51
49	486.00	64,767.51	64,767.51
Aggregated values			
Median	325.00	5,284.37	8,144.85
1st Quartile	185.00	112.63	817.06
3rd Quartile	900.00	38,653.54	49,021.18

Table 1—Descriptive statistics of the CIC historical data from Jan - May 11 2020

State Variables	Purpose
network	Multi-directed graph in NetworkX object[Hagberg et al., 2008]
KPIDemand	Subpopulation demand from the timestep in dictionary format
KPISpend	Subpopulation spend from the timestep in dictionary format
KPISpendOverDemand	Subpopulation spend divided by demand in dictionary format
VelocityOfMoney	Velocity of money from the timestep
startingBalance	The starting subpopulation CIC balance in dictionary format
30_day_spend	Subpopulation spend over the last thirty timesteps
withdraw	Subpopulation actual withdraw, in dictionary format
outboundAgents	Subpopulation agents that are paying during the timestep.
inboundAgents	Subpopulation agents that are receiving during the timestep
operatorFiatBalance	Currency operator Fiat balance.
operatorCICBalance	Currency operator CIC balance
fundsInProcess,	Dictionary of Dictionaries that records funds awaiting settlement
totalDistributedToAgents	Total amount of CIC distributed to agents during the simulation
totalMinted	Total amount of CIC minted during the simulation
totalBurned	Total amount of CIC burned during the simulation

Table 2—State variables for the economic system simulation