Barter Markets, Mediums of Exchange and Social Relations of Mutual Insurance

by Guido Russi

> *That the economists can't measure any of their quantities even to their own satisfaction, can explain neither prices nor the rate of interest and cannot even agree what money is, reminds us that we deal here with belief not science. (J. Buchan)*

In spite of the stark position taken by Buchan in the above quote, it is true that the subject of money has been the subject of a long and ongoing scholarly debate, with inquiries into the generality/particularity of money, its state or commodity basis, its expression of and distortion of social relations, its relation to nationality and its relation to "real" accumulation, to name but a few (Bryan and Rafferty, 2007: 135).

General consensus exists on the fact that money can perform four main functions: medium of exchange, measure of value (unit of account), storage of value, means of unilateral payment/settlement (Ingham, 2004 and Kunigami et al., 2010). Yet, economists still struggle to explain historical periods in which one or the other function seemingly disappeared. Specifically, the following questions remain unanswered (Ingham, 2004):

- Is there any specific feature of money which confers "moneyness" upon it? Is there a feature which helps define money in a unique manner?
- Are the four main functions of money all essential for "moneyness" to arise? For instance, is money a payment means because it is a store of value? Or is it instead a store of value because it is accepted as a means of debt settlement? Does a medium of exchange spontaneously acquire its own uniform value standard or should the existence of some abstract measure of value (money as unit of account) precede the emergence of a medium of exchange?
- How does money emerge in an economy? Could decentralized barter exchanges based on individual subjective preferences produce a uniform standard of value? Could a measure of value develop from individual solutions to the inconveniences of barter?

The objective of this paper is to investigate the latter question. Indeed, understanding why money gets into an economy could be fundamental to developing sound answers to the previous two questions.

Monetary Search Theory and Agent-Based Modelling

Orthodox economic theory sees money as a "neutral veil" in a world where output and growth are determined (at least in the long run) by real forces of the economy (Ingham, 2004). In the Arrow-Debreu economy, exchange ratios among commodities are the critical variables hidden behind money prices. Money, as a highly liquid commodity, can simply be introduced as a factor that lubricates exchange. The key contradiction within this approach is that in an Arrow-Debreu economy where all conceivable contingent future contracts are known, agents would not need and would not put a positive price on money (Hahn, 1982: 1).

Modern monetary theory therefore started departing from general equilibrium value theory to explain the emergence of money and, instead, focussed on the actual realization of exchanges within an economy free from a centralized organization of transactions (Alvarez, 2004: 53). In particular, search monetary theory represents the most significant attempt to model the emergence of money out of non-cooperative bilateral exchanges (see, eg, Lagos, 2010).

Whilst the development of these micro-founded models represents an important step forward in explaining the emergence of money, search monetary theorists still heavily rely on strong assumptions about hyperrationality, utility maximization and information availability as well as on the usage of representative agents. (Gilbert, 2008:1-20).

In this context, Agent-Based Modelling–a new analytical method for the social sciences–could represent a viable theoretical alternative. Agent-Based Modelling consists in the study of economy-wide patterns that emerge from the actions and interactions of individual agents. In Agent-Based Models, heterogeneous agents interact with each other in an environment and they do not necessarily have perfect knowledge of the rules and mechanisms that are embedded in the environment or of the strategies and payoffs of other individuals. Instead, their actions are driven by very simple behavioural rules. Because of these features, Agent-Based Modelling represents an innovative approach to modelling information acquisition and distribution, strategy and choice (Gilbert, 2008:1-20). Economy-wide patterns may then emerge, which could not have been predicted based on the initial behavioural rules.

Agent-Based Modelling therefore appears to be a useful approach in trying to understand how money gets in the economy, especially in light of the focus placed by Agent-Based Models on social interactions. This work represents an attempt to use these models to explain the emergence of money.

Idea behind this model

The idea can be summarised as follows:

- Specialization (ie. production of goods other than those consumed) generates a need for exchange among agents. As described by Adam Smith (1776), the emergence of money is mainly a consequence of specialization, ie. the fact that agents do not necessarily consume what they produce.
- In barter markets, such exchanges are characterized by the problem of the double coincidence of wants, ie. exchange is made more complex by agents' necessity to find the "right" counterparty (one that wants what is being offered and that sells what is being demanded). The double coincidence of wants is treated as a **risk** in this model. This was noted by Jevons as far back as 1875, who noted three inconveniences to simple barter, "namely, the improbability, of coincidence between persons wanting and persons possessing; the complexity of exchanges, which are not made in terms of one single substance; and the need of some means of dividing and distributing valuable articles" (Jevons, 1875).
- Also, barter market transactions may take place between parties that cannot commit to long-run solutions, due to their anonymity, ie. the fact that their past transaction history is not public information. This anonymous trade and the associated commitment problems have been the object of several academic studies that have investigated how these issues are overcome in an economy (eg, Lagos, 2010 and Rupert et al., 2000).
- Consequently, individuals' remedies to these problems should (i) **alleviate risk**, and (ii) **increase individuals' capability to commit**. This paper tries to understand whether **self-interested bilateral/multilateral pooling of resources** (social relations of mutual insurance) could represent a self-sustaining solution to the problems above.
- Confirmation/rejection of the above hypothesis may shed light on the relation between barter transactions and monetary transactions (substitutes vs complements) and on the role of national authorities in supporting monetary economies.

If money is to arise out of individuals' responses to the inconveniences of barter and these inconveniences are assumed to be the **risk of not finding a counterparty** and **commitment problems** (for the reasons argued above), then money should exhibit the following features:

- It should be the product of the actions, interactions and decisions of **self-interested** individuals. This paper does not assume altruism, nor rule out cooperative solutions to the inconveniences of barter.
- It should reduce the risk of not finding a counterparty, ie. it should represent **a form of insurance** to the individual.
- It should increase agents' credibility and **capability to commit.**

Based on these insights, the emergence of money is then modelled as follows:

- Engaging in decentralized negotiations before production, agents offer each other resource-pooling agreements (similar but not equal to insurance contracts) whereby they agree to pool all of their production in exchange for a guarantee of a minimum level of consumption ("insured" level). These offers are accepted or rejected by agents based on their expectations of future production and on their consumption targets.
- Production then takes place and, if agents have agreed to pool resources, they give up their production in exchange for a basket of goods equal to the minimum level of consumption guaranteed. The resource transfer system can be designed in several manners but, in this paper, one specific transfer method is explored: the minimum level of resources guaranteed is transferred in kind. Any excess commodities are instead kept by the producer. Conversely, in the event of production deficits, no resource transfer occurs but individuals that end up without the commodity are instead assigned a token that represents a share of the excess commodities (different in species) in the social network. A real-life parallel to these arrangements would be the taxation and spending activities that characterize monetary economies in different forms (a *de facto* provision of consumption insurance). Monetary and barter transactions can then occur within a network, as agents adjust their consumption basket.

- Decentralized barter transactions then take place, with agents that have pooled resources potentially using money as part of their bids.
- Based on the success of barter transactions, on the evolution of uncertain production and on agents' revisions of expectations, resource-pooling agreements are renewed or terminated, thus allowing for monetary economies to emerge, but also to fall–a real-life phenomenon noted by several scholars (eg, Kunigami et al., 2010: 69-70).

These dynamics are discussed in further detail below. As pointed out, this article only tests the survival of one type of social arrangement. It does not posit that this would be the only type of social arrangement possible. Nevertheless, testing whether such social arrangements can survive and whether they end up substituting/complementing barter trade arguably represents a significant contribution to the debate on the ontology of money.

Description of the model

The economy comprises a variable number of infinitely-lived agents. There are three non-storable, perishable and indivisible consumptions goods. Improving from previous models (eg. Kiyotaki and Wright, 1989: 931), the assumption of indivisibility is not accompanied by an assumption of one-to-one exchange ratios (see below). Each agent produces an uncertain quantity (going from 0 to 10 units) of each commodity. Agents can produce 0, 1, 2, or even all 3 goods. Each period, agents' production of each good can increase by one unit, decrease by one unit or remain at the same level. This change need not be the same for all goods. Specialization is modelled by assuming that each agent has a random 'consumption target' for each good (again, 0 to 10 units). This consumption target is equivalent to agents' demand or preferences and it is allowed to evolve over time, with only two constraints: (i) agents' consumption targets cannot at any point in time exceed their expectation on what they will be able to consume via production and/or exchange in the future (in the next period); (ii) if this expectation increases, agents gradually revise their consumption targets upwards. Specialization is present despite these constraints: agents are still (very) likely to desire goods which they do not produce (just like in Trejos and Wright, 1995: 120), even though this may also not be the case for a subset of agents. The model assumes adaptive expectations: agents' expectations of future consumption possibilities (for the next period) are based on the sum of (i) the level of production experienced in the previous period and (ii) the additional consumption possibilities achieved through exchange in the previous period. Importantly, this is a simplifying assumption which can be relaxed without undermining the overall theoretical framework.

Time is discrete and the horizon infinite. Each time period is divided into two subperiods: a pre-production period and a post-production period. These subperiods are described below.

Pre-production period

The first subperiod starts with a set of decentralized "insurance" negotiations among agents, who approach other agents (or pre-existing 'monetary' social networks) and check whether a resource pooling agreement is possible which is both:

- **Convenient.** Agents only agree to an insurance that grants them a certain (zero-risk) level of consumption higher than their consumption target and not much lower than their expected consumption possibilities (which in turn are based on their past production and trade performance). If the contract promises to yield a consumption basket that is well below what the agent could achieve by operating individually, the agent prefers not to enter the contract.
- **Feasible.** Agents do not enter in contracts that promise to guarantee a level of consumption that is unrealistic given the expected aggregate production (and exchange) of all prospective members. This second condition relies on truthful revelation of consumption expectations and consumption targets by the agents. Whilst this simplifying assumption is clearly unrealistic, it should be noted that non-truthful revelations would be short-lived under the workings of this model, as explained below.

If these two conditions are met, agents agree on an "insured" level of consumption for each good (which will then be higher than the individual target of both agents).

Post-production period

Once insurance negotiations terminate and "monetary" social networks are formed, production occurs and agents learn whether their outturn production meets their expectations. Based on this, they prepare for decentralized barter transactions, as follows:

— **Settlement within monetary social networks.** Agents that have struck mutual insurance agreements share goods as follows. For each good, if aggregate production within the network exceeds the insured level, goods are redistributed (no immediate and reciprocal profit is required, as would be the case in barter transactions) and excesses are left with their producers. If instead aggregate production is below the insured level, agents that have produced more than the insured level keep an amount equal to the insured level and the rest is pro-rated across "unlucky" agents that have produced less than the insured level.
Borrowing from Lagos' (2010) idea of a commitment device, the model assumes that unlucky agents that have produced less than the insured level are also awarded a token that will symbolize a share of the overall surpluses present in the economy. Agents will be able to exchange this token in barter transactions and, since this token represents an obligation backed by the entire excess surplus of the economy, it will contribute to increase the agent's credibility.
Agents will also engage in barter and monetary exchanges within the network to tailor the redistribution mechanism to their personal preferences. It should be noted that, since taxes will have to be paid with money, agents with excess productions will have incentives to accept money.

— **Decentralized barter market sessions.** Following settlement of mutual insurance obligations, decentralized barter market sessions start. Agents exchange only if they find a counterparty that can fill all the commodity deficits of the agent. Indeed, if this were not the case, agents could agree to trades that may leave them with still some commodity deficits but also without commodity surpluses to use in other exchanges. If an agent finds such counterparty, the two agents' commodity deficits are evened out. It is important to note that this structure innovates by (i) allowing for barter between a commodity and a bundle of commodities, and (ii) allowing for flexible exchange ratios (the imposition of one-to-one exchange ratios has been criticized, eg, by Trejos and Wright, 1995: 119). In these barter exchanges, tokens are exchanged too, based on the share of the commodity surpluses of the associated monetary network. The tokens are converted at the end of the period by the agent in possession of the token.

At the end of the above process, agents consume and revise their expectations and agreements of mutual insurance are revised or rescinded in the following manner:

— **Expectation revision.** Based on what an agent has been able to produce and exchange (through mutual insurance, barter transactions or monetary transactions), expectations on the consumption possibilities of the agent for the next period are formed. Given the linkage between the consumption target and expectations, the revision of expectations also leads to a revision of consumption targets by the agents.

— **Appraisal of mutual insurance agreements.** Within a monetary social network, agents that have experienced positive production shocks may no longer find the agreement convenient (one of the two key conditions) and therefore leave. If an agent leaves a network, it will form expectations only based on their personal production, not on the commodities gained through exchange (performance in exchange was affected by the insurance agreement and cannot be relied upon in the future if leaving the agreement). To give the network a possibility of surviving, this work therefore assumes that agents will revise the insured level upwards to avoid the loss of agents with high production levels. Increasing the insured level, however, can result in the agreement not appearing feasible any longer (the second key condition). Consequently, monetary social networks can withstand only small and/or brief asymmetries in production.

Once expectations are revised and agreements are appraised, the economy moves to the next period, and the cycle is repeated, with monetary networks forming or expanding and so on.

This structure therefore contains both centripetal forces that can trigger the creation of monetary social networks (agents' desire to reduce barter market risk) and centrifugal forces that can break these social networks apart. Observing the evolution of the model for an extended number of periods can therefore yield information on (i) the survival of these networks, (ii) the relative predominance of barter transactions and monetary transactions, (iii) the attainment of monetary equilibria and/or barter equilibria or otherwise.

Description of the code

The simulation described above was undertaken using the software NetLogo. The sections below contain a description of the code.

Description of the turtles

The model contains two types of turtles: **agents** and **representatives**. Agents are individuals which produce, exchange and consume. Their primary attributes (Fig. 1) are:

— **Basket:** a basket where the agent's production of the 3 goods is placed;

— **Target:** the agent's consumption target. By construction, the target cannot exceed the agent's expected production for all 3 goods;

— **Consumption:** this is the basket where the agent accumulates goods throughout the execution of a cycle for consumption at the end of each cycle.

Agents' colouring can change to red, yellow or green, depending on whether the current contents of their consumption basket exceed the contents of the target basket.

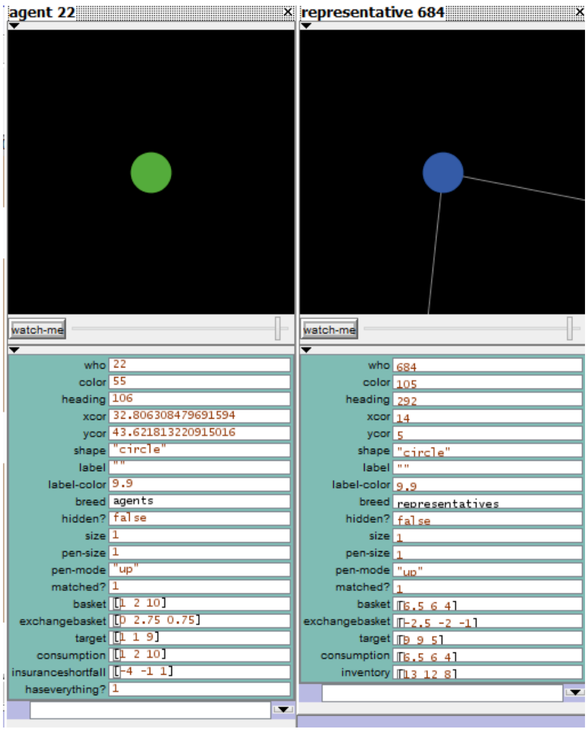


Fig .1–An agent and a representative

Representatives, instead, are turtles hatched when a monetary network is formed. Their purpose is mainly that of keeping the "accounts" of the network. Their key attributes (Fig. 1) are named after the variables of the agents but do not necessarily play the same role:

— **Basket:** represents the average production basket within a network;

— **Target:** this attribute represents the agreement among agents in a monetary network. This attribute is indeed the "insured" level of consumption that agents have agreed on. By construction, it will be higher than the target of any of the agents in the network;

— **Consumption:** this attribute is very different from agent's attribute "consumption". For representatives, "consumption" contains the average consumption achieved by the members of the network;

— **Inventory:** this variable temporarily holds the goods produced by the network on aggregate, during the process of redistribution (described in the next sections).

Setup

When the button "Setup" is pressed, agents are generated. The user can select the number of turtles and can decide to insert some "controlled" agents, ie. agents whose initial production is specified by the user, instead of being random. This type of agents will be shaped as triangles (see Fig. 2).

Also, at setup, the world is generated and divided into two parts. On the right (Fig. 2), there is an *agentspace*, where agents and representatives move, trade, and form monetary networks. On the left, 6 barter markets are drawn. These barter markets will display the number of barter transactions that take place in the *agentspace*. It is important to observe that barter transactions could also involve exchanges of a commodity for a bundle of commodities. These "commodity-bundle" markets are included in the group of 6 barter markets on the left side of the world.

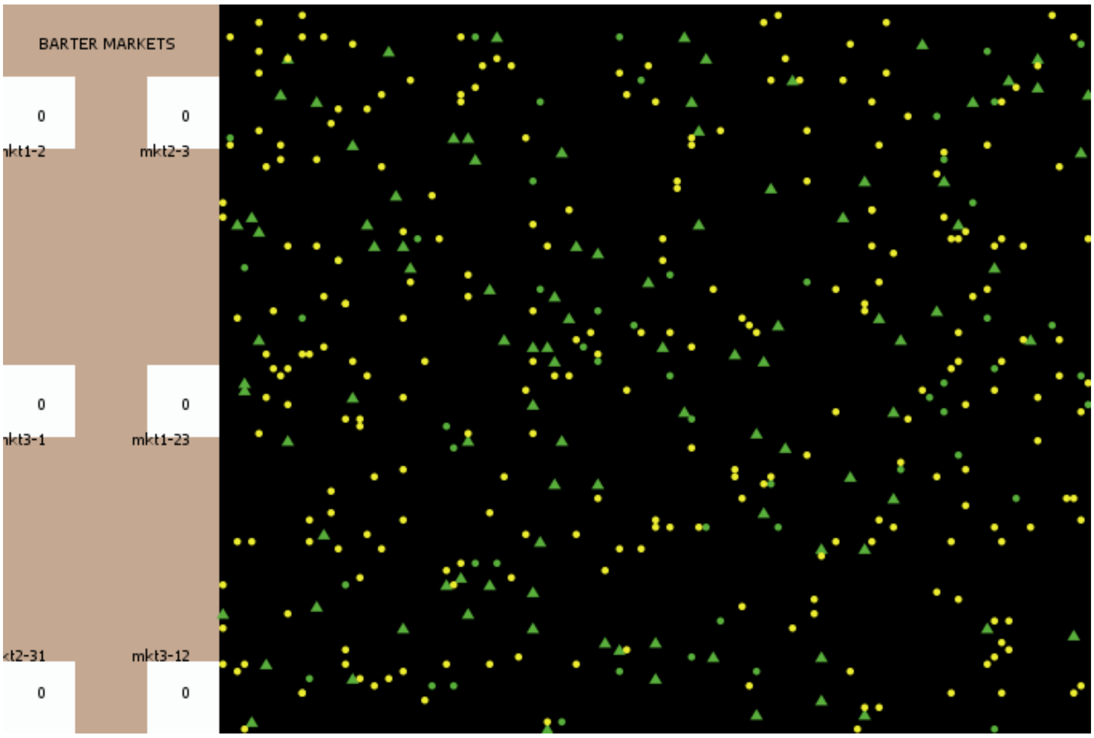


Fig. 2–The world at setup

Execution

The model is based on the cycle represented below.

```
to go
  if ticks <= Max_No_Cycles [
    ifelse ObservationPauses? [set pause 1] [set pause 0]
    clear-output
    output-show "Teams are forming..."
    formteams
    output-show "Teams are formed"
    output-show "Production expected soon..."
    reset-timer
    while [timer < pause * 2] []
    produce
    collect
    internalaccounting
    updateexchangebasket
    determinemktposition
    output-show "Production completed"
    output-show "Trade expected soon..."
    reset-timer
    while [timer < pause * 2] []
    trade
    moneyconversion
    fixmktcolors
    updatetargetsandteams
    output-show "Targets being revised"
    output-show "Color updating expected soon..."
    reset-timer
    while [timer < pause * 2] []
    determinemktposition
    output-show "End of cycle"
    tick
  ]
end
```

This cycle comprises numerous procedures but the five main ones are:

— **Formteams:** in this procedure, decentralized bargaining sessions take place. Agents are matched and they may create or join a monetary network. At this stage, agents do not know what their outturn production for the period will be.

— **Produce:** once networks are set up, nature reveals to the agent what its production will be for the period.

- **Internalaccounting:** upon termination of the production process, agents in monetary networks redistribute production among themselves. Rules for the allocation of commodity surpluses and deficits (relative to the representative's target) are applied at this stage. In the event of an aggregate production shortfall, tokens (money) are issued to some of the agents.
- **Trade:** agents that still have production deficits after all previous stages enter a decentralized barter market session. Agents find a match if they run into an agent that has offsetting production surpluses and deficits. Tokens can also be used as a medium of exchange in these market sessions. Transactions with members of the same network are priviledged.
- **Updatetargetsandteams:** after barter transactions have taken place, agents revise their expectation on their future possibilities of consumption (which they base on the performance in production and trade in that period) and also adjust their targets accordingly. Representatives do the same. At this stage, agents may leave networks if they no longer find them convenient and networks can therefore break up.

These procedures are described in further detail below.

Formteams

During this procedure, agents outside of networks and representatives take part in 50 rounds of negotiations. In each of these rounds, participants are paired. In each pair, a *commontarget* is calculated, which represents the prospective level of insured consumption that the two participants would agree on. The calculation is the following (*target* and *temp* are the targets of the two participants that have been coupled):

```
let commontarget (map [ifelse-value (?1 > ?2) [?1] [?2]] target temp)
```

For each commodity, *commontarget* will contain the highest target level of consumption of the two participants. In other words, two parties will agree to a mutual resource pooling agreement only if the basket of consumption guaranteed by the agreement is as high as the level of consumption that they would be targeting individually.

Once *commontarget* is calculated, the two coupled participants check that the agreement is convenient (ie. that it guarantees a level of consumption not too far below their expected production) and whether the agreement is realistic (ie. the aggregate expected production of the two parties exceeds the level of consumption guaranteed in the agreement). The code for these two conditions is reported below, where *temp2* and *temp5* represent the production expectations of the two agents.

```
not (min (map - temp5 commontarget) >= 1
or min (map - temp2 commontarget) >= 1
or min (map [v * ?1 + s * ?2 - (v + s) * ?3] temp2 temp5 commontarget) < 0)
```

If these conditions are satisfied, the agents form a network and a representative is hatched. The representative creates a directed link to the two parties. Figure 3 depicts the outlook of the world upon completion of the 50 rounds of negotiations.

During this procedure, agents can also be matched to representatives and can decide to join the representative's network. Two representatives can be matched, too, and they can decide to merge their two networks. The same conditions specified above apply to representatives, too, and convenience and feasibility remain the two criteria used to decide whether to enter an agreement or not.

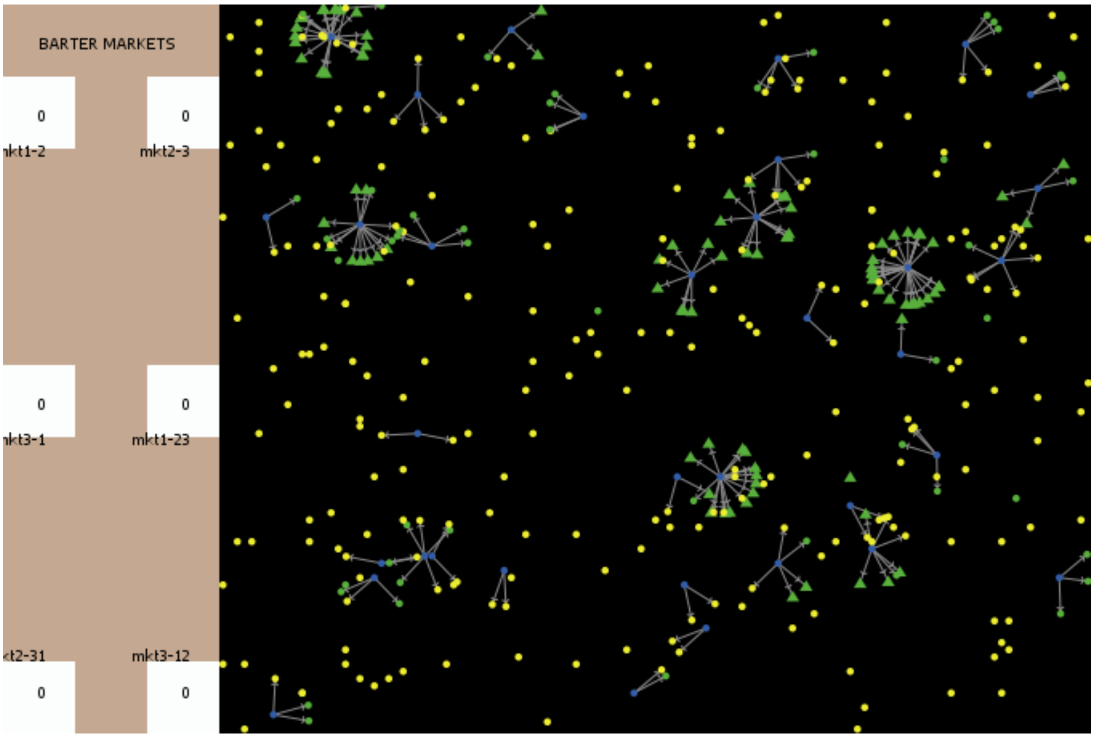


Fig. 2–The world after monetary networks are formed

Produce

After monetary networks are set up, production occurs. At the start, each agent produces a random quantity (going from 0 to 10) of each commodity, with the *to-report* method shown below. It is important to note that this code results in the quantity produced being drawn from a uniform distribution. More complex distributions (eg. Gaussian) could be modelled, too.

```
to-report drawbasket
  let draw []
  let temp 0
  foreach n-values 3 [1] [
    let i floor random-float 22
    ifelse i < 2 [set temp 0] [
      ifelse i < 4 [set temp 1] [
        ifelse i < 6 [set temp 2] [
          ifelse i < 8 [set temp 3] [
            ifelse i < 10 [set temp 4] [
              ifelse i < 12 [set temp 5] [
                ifelse i < 14 [set temp 6] [
                  ifelse i < 16 [set temp 7] [
                    ifelse i < 18 [set temp 8] [
                      ifelse i < 20 [set temp 9] [set temp 10]]]]]]]]]]
    set draw lput temp draw]
  report draw
end
```

For a subset of "controlled" agents, this quantity will not be random, but will instead be specified by the user.

After the initial period, production is no longer random, but evolves according to random unitary shocks (positive, negative, or zero shocks). The relative code is shown below. Again, the shocks are drawn from a uniform distribution.

```
ask agents [
  foreach n-values 3 [?] [
    set basket replace-item ? basket (max (list 0 (min (list 10 (item ? basket + (random 3) - 1) ) ) ) )
  ]
]
```

Based on their consumption target and on the outturn production, agents are then coloured either in green (agents with production surpluses only), or in red (agents with production deficits only), or in yellow (agents with production surpluses for some goods and production deficits for some other goods). This is shown in Figure 3.

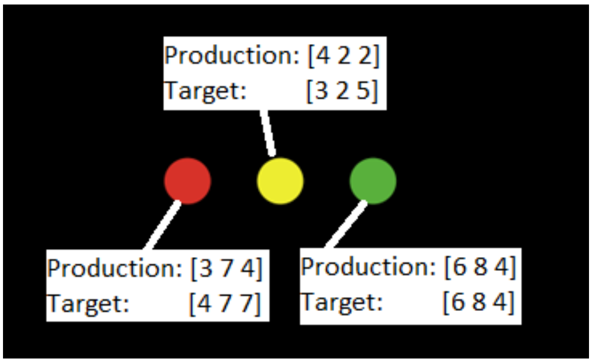


Fig. 3–Colouring of agents

Internalaccounting

In this procedure, redistribution within monetary networks occurs. Representatives symbolically place agents' production in the inventory. Representatives then follow a set of rules to allocate production to the members of the network:

- if the aggregate production of a commodity is sufficient to meet the insured level (the value specified in *commontarget*), the representative allocates a portion equal to the insured level to all agents; any excess is symbolically left with the representative (in the inventory);
- if the aggregate production of a commodity is not sufficient to meet the insured level, agents that have produced more than the threshold are allocated a portion equal to the insured level; the remainder is shared in equal portions across "unlucky" agents whose production has not met the minimum insured level;
- to compensate agents that—after the redistribution—have received quantities of some commodity in deficit relative to the insured level, representatives give each of these "unlucky" agents a token, that represents an equal share of the surplus commodities in the network's inventory.

The tokens issued in this process are modelled as directed red links from the representative to the agent, as shown in Figure 4.

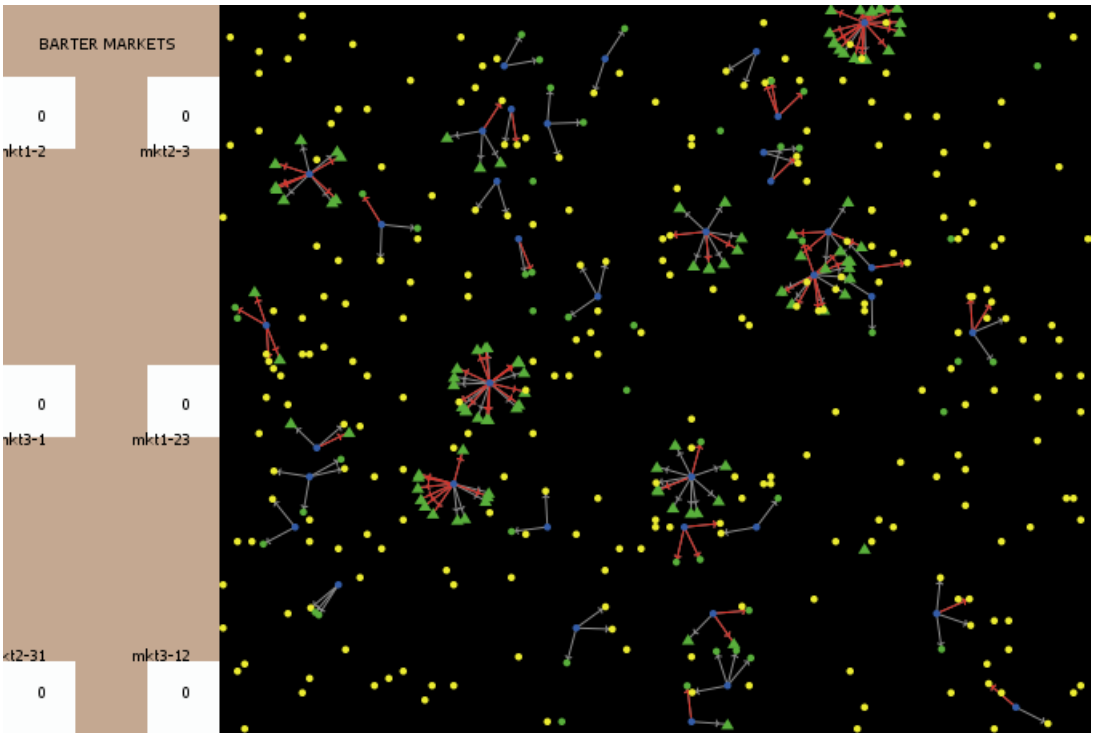


Fig. 4–Outlook of monetary networks after redistribution of resources and issuance of tokens

Trade

After internal settlement within monetary networks is completed, decentralized barter market sessions start. During these sessions, agents exchange only if the prospective transaction would eliminate all commodity deficits for both parties. Were this assumption not in place, agents would risk exchanging all of their commodity surpluses without extinguishing all of their commodity deficits and without having anything to offer in subsequent transactions. An example can help clarify this point (see also Figure 5):

- Agent A wants a unit of good 1 and 2 units of good 3 and has an extra unit of good 2 to offer. Agent B wants one unit of good 2 and has an extra unit of good 1. Exchange does not occur. Else, Agent A would be left with no commodity surpluses to exchange for the 2 units of good 3 he still needs.
- Agent A wants a unit of good 1 and 2 units of good 3 and has 2 extra units of good 2 to offer. Agent B wants one unit of good 2 and has an extra unit of good 1 and 3 extra units of good 3. Exchange occurs. Agent A receives a unit of good 1 and 2 units of good 3 and transfers one unit of good 2.

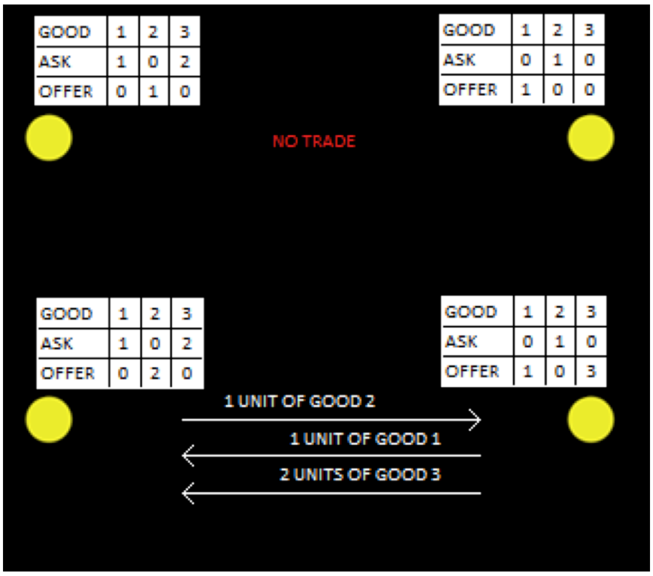


Fig. 5–Examples of valid and invalid barters

Exchange occurs initially within members of the same network and, if necessary, agents then extend negotiations to agents outside of the network, too.

Throughout these negotiations, agents may also use tokens as a medium of exchange. These tokens will be considered equivalent to the share of production surpluses held by the relevant representatives. Possession of the tokens, however, does not entail actual usage of the coins in barter market transactions. Usage of tokens occurs only if necessary to make the transaction viable. At the end of the cycle, tokens will be redeemed by the possessor, who will receive the corresponding goods from the representative. Figure 6 below shows the network of monetary exchanges and the activity in barter markets during this part of the cycle.

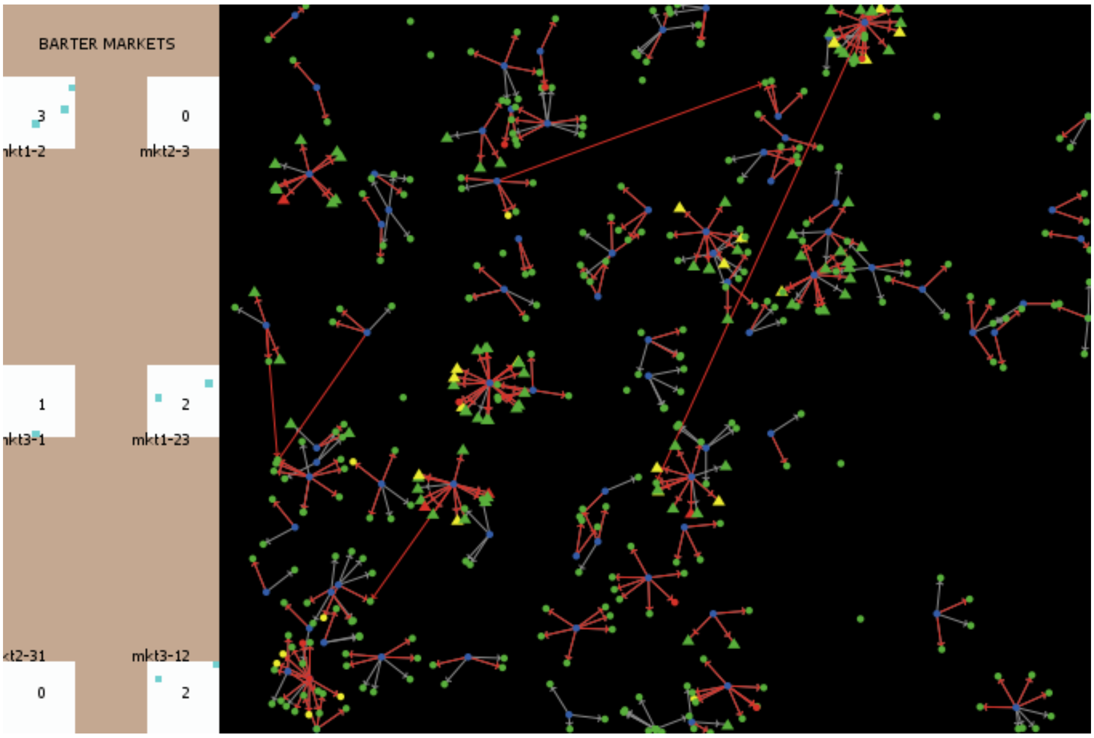


Fig. 6–Barter market activity and monetary exchanges during trade sessions.

Updatetargetsandteams

At the end of the cycle, all agents revise their consumption targets and decide whether to leave the networks.

Specifically, in this model, it is assumed that agents' consumption targets cannot exceed their expectations of future consumption possibilities. Future consumption possibilities, in turn, are estimated based on current consumption, ie. the sum of current production and current trade balances (see below).

```
ask agents [
  foreach n-values 3 [?] [
    ifelse item ? consumption <= item ? target [
      set target replace-item ? target max (list 0 (floor item ? consumption))
    ]
    [
      set target replace-item ? target min (list 10 (item ? target + floor (0.5 * random 3)))
    ]
  ]
]
```

Hence, if consumption is lower than the initial target, the target is revised downwards. If consumption exceeds the initial target, the initial target is increased by one unit (30% of time). The increase in the consumption target is left gradual to avoid that the target ends up being identical to the current consumption level.

Based on agents' revision of consumptions targets and of expectations of future consumption possibilities, monetary networks can lose members or even break apart. Indeed, agents that experience surges in production will have fewer incentives to remain in a monetary network (ie. they will find it less convenient). Representatives therefore re-compute *commontarget* in an attempt to retain agents with high production levels. However, if only few agents experience production surges, raising the *commontarget* may make the agreement unfeasible (see explanation in previous sections). Hence, if a monetary network experiences asymmetric production shocks for a sustained period of time, its representative will not be able to retain all members indefinitely and membership of the network will eventually have to change.

Measured variables

Throughout the cycle, a number of measurements are performed: the number of agents choosing to join monetary networks, the number of agents choosing not to do so, the size of monetary networks and the number of different types of transactions.

With respect to the latter measurement, it is important to emphasize that exchanges can occur within a network or across networks. Specifically:

— **Within a network,** a set of internal resource transfers precedes a set of internal barter transactions and monetary exchange among agents, who tap internal exchange possibilities before resorting to external transactions. All three types of transactions are measured. Importantly, internal barter transactions represent consumption readjustments within the insured target. Production in excess of the insured level can only be traded through monetary exchanges (as tokens represent such excess product).

— **Across networks**, agents can engage in barter transactions or in money-mediated transactions. Both types of transactions are measured.

In measuring these 5 types of transactions, the following principle is followed: **monetary exchanges and internal transfers are counted based on the number of barter transactions they replace.** Specifically, internal transfers are counted only if they help the recipient achieve the insured level of consumption and its personal consumption target and avoid market transaction within or across networks. Monetary transactions are counted based on the number of barter transactions they replace (eg. issuance and redemption of a token count as one transaction).

Experimental results

Baseline model

Initially, a baseline simulation is undertaken, starting with 400 agents and running 200 cycles. No controlled agents are present at this initial stage. Monetary networks rapidly emerge, as "homogenous" agents find mutual insurance agreements both convenient and feasible. The outlook of the world at the start of the simulation is shown in Figure 7 below.

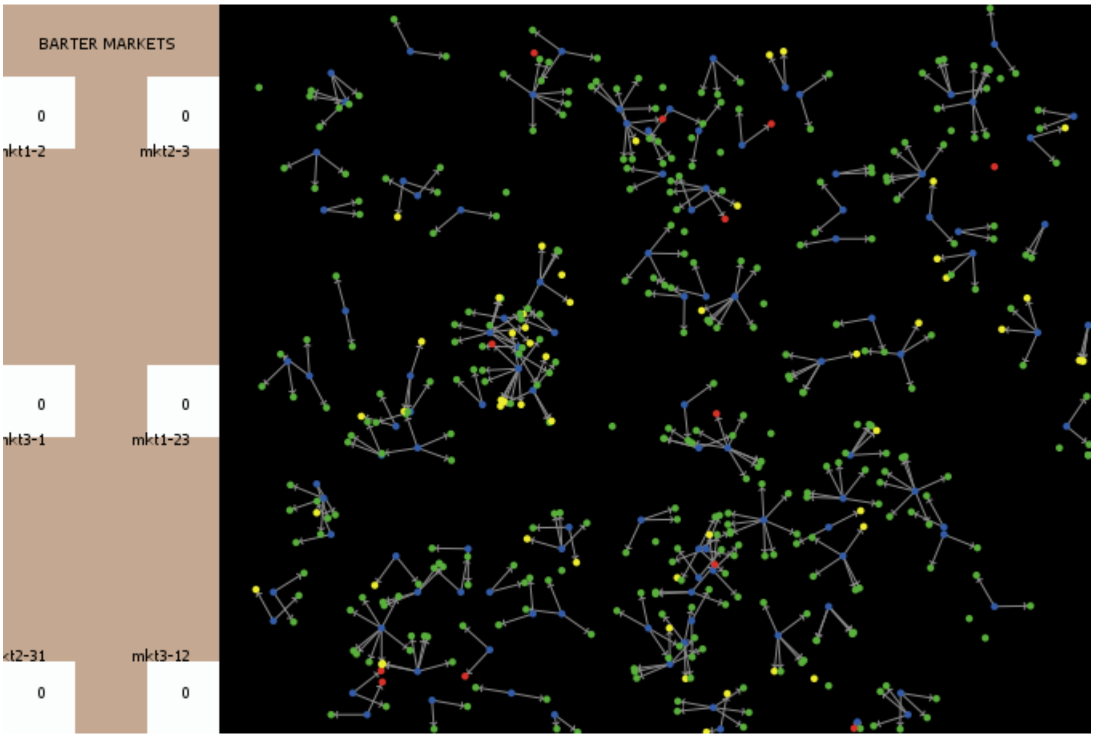
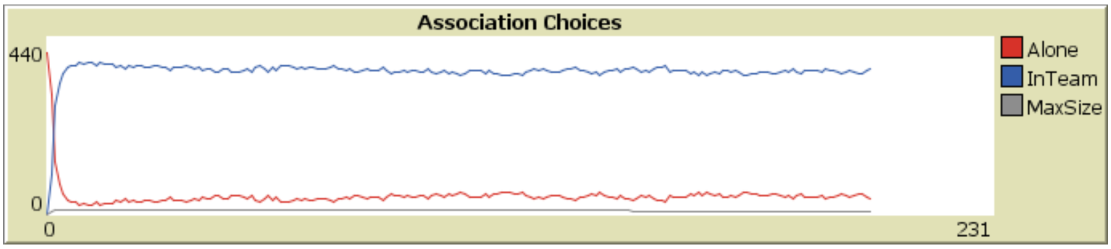
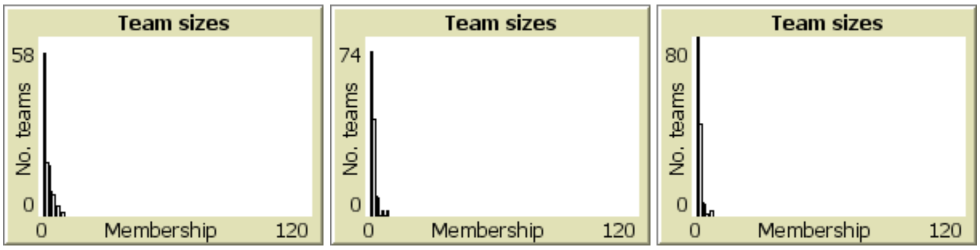


Figure 7–Outlook of the world at the start of the "baseline" simulation

During the 200 cycles, the number of agents in monetary networks and the number of agents acting individually does not vary substantially, as shown in the plot below.



Also, the size of monetary networks remains on average relatively small, with no tendency to "macro-aggregations". The three plots below (from left to right) show the gradual change in the distribution of network sizes (no significant change in this simulation).



The data above however masks the frequency with which agents end up leaving networks. As shown in Figure 8, indeed, most of the networks observed after 200 cycles are predominantly different from the ones observed at the start (note: networks do not move around over time whereas new networks are placed in random places).

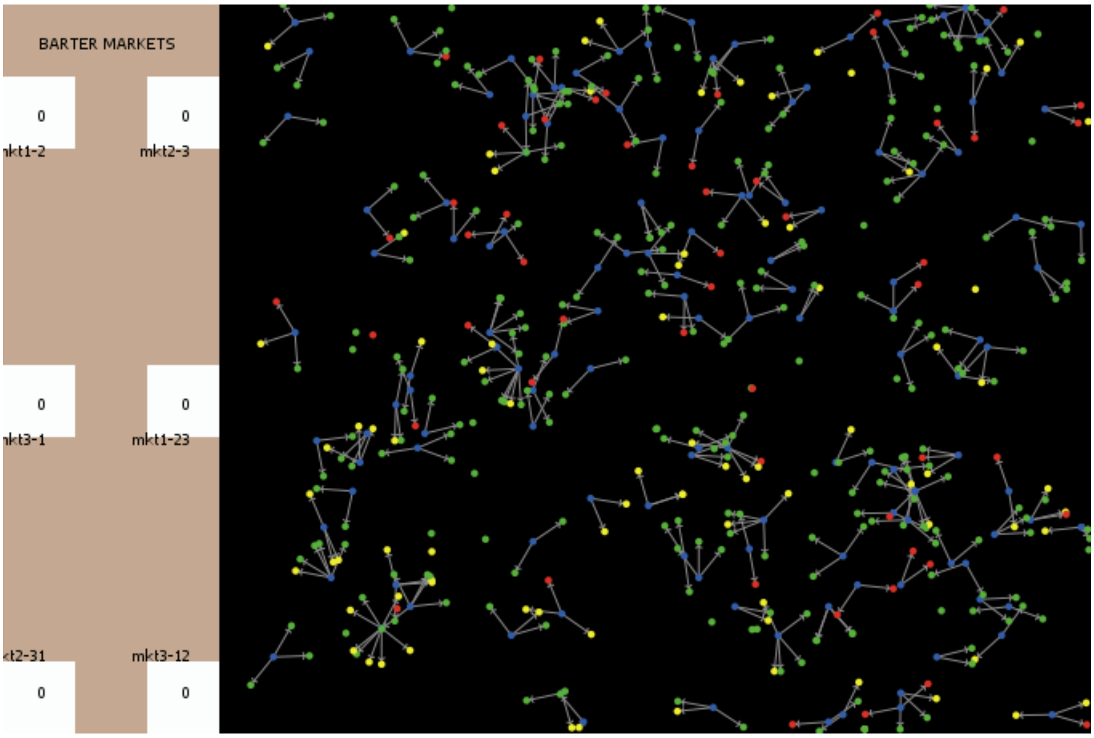
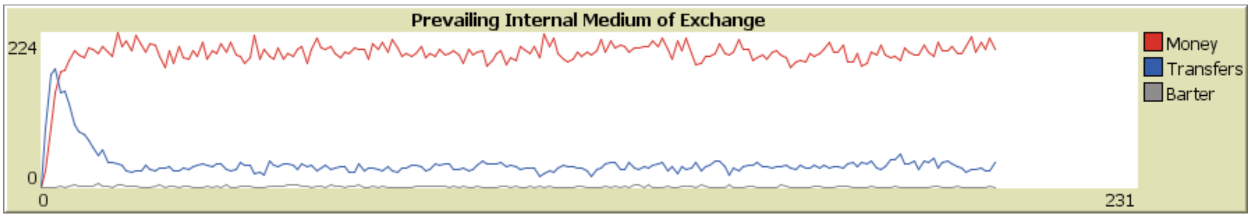
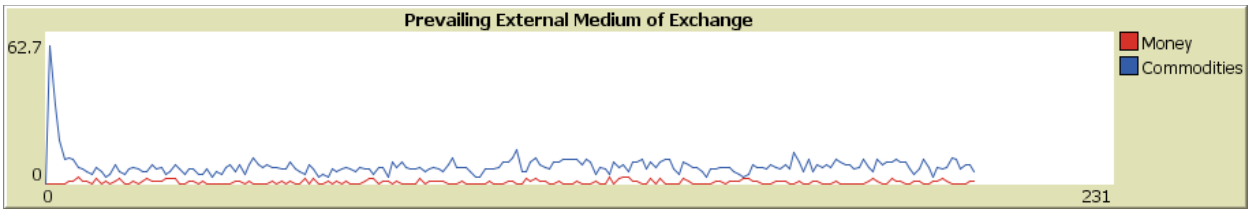


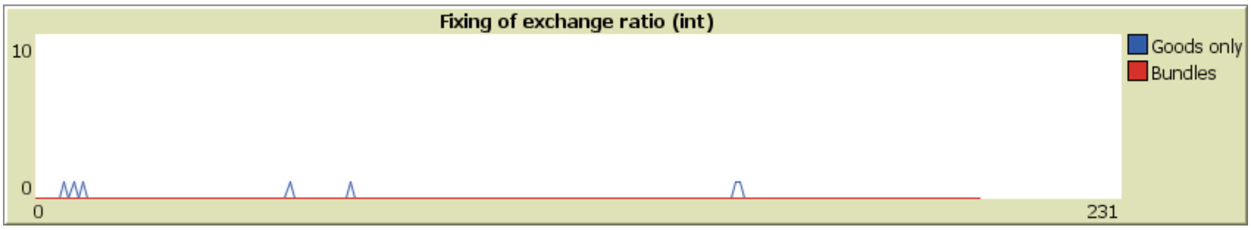
Figure 8–Outlook of the world at the end of the "baseline" simulation

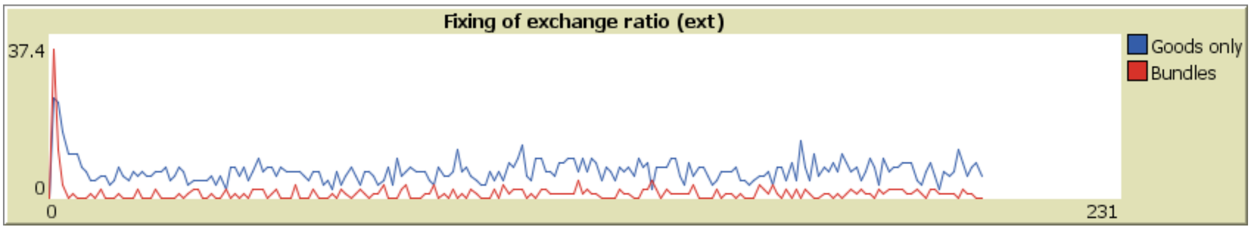
In addition, plots of the different types of transactions (shown below) reveal that monetary networks end up resorting to the issuance of money very frequently. This money, however, is spent predominantly inside the network, as agents appear to be able to achieve their own personal consumption targets through internal monetary transactions. Barter transactions, instead, are relatively infrequent within networks and are predominant (although still scarce) in exchanges outside of the boundaries of monetary networks.





Barter transactions are scarce within monetary networks and, when they do occur, they involve the exchange of one commodity with a different one. Conversely, barter transactions outside of monetary networks—which are relatively more frequent—also comprise exchanges of single commodities with bundles of commodities. This trend is depicted in the plots below. The upper plot shows the number of barter transactions within a network involving "goods only" and of barter transactions involving "bundles". The lower plot shows the same variables for transactions across networks.





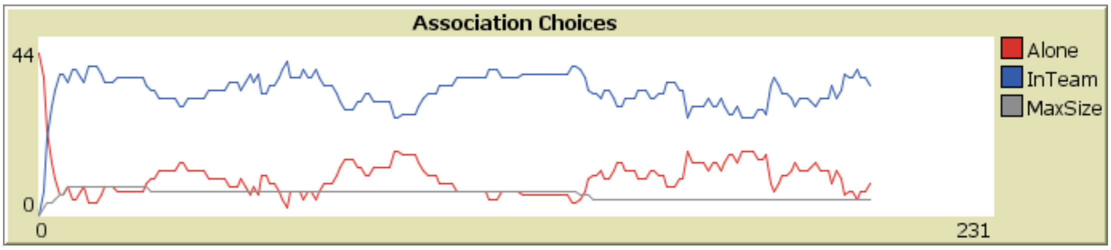
To further investigate the trends described above, two variations to the baseline simulation are undertaken:

- **Reduction in the number of agents.** This variation may help understand why monetary networks appear so unstable. Indeed, by reducing the number of agents, agents searching for networks should have higher chances of running into agents similar to them, eventually. Also, the expected smaller size of teams should result in speedier disintegration of monetary networks with heterogeneous agents and, therefore, more frequent revision of network membership by agents. With a lower number of agents, homogeneity within some (but not all) monetary networks should gradually increase and the development of a few large monetary networks would be expected.
- **Artificial introduction of homogeneous agents**. The introduction of "controlled" agents that are initially homogeneous may help understand why monetary networks appear so unstable. Indeed, "controlled" agents are likely to join the same monetary network in the first few cycles. This network is expected to survive due to the initial homogeneity of its members, as well as the large size it immediately acquires. Survival of this network would imply that achievement of a critical mass can help overcome asymmetric shocks in the productive rates of members.

The simulations associated to these variations are described in the paragraphs below.

Variation 1: reduction in the number of agents

By reducing the number of agents to 40, the switching rate increases as expected. The plot below shows how unmatched agents are sometimes close to the number of agents in networks.



Comparison of the world at the start and at the end of the simulation (Figures 9 and 10) shows that, as expected, some initial networks do survive, although their size remains relatively small.

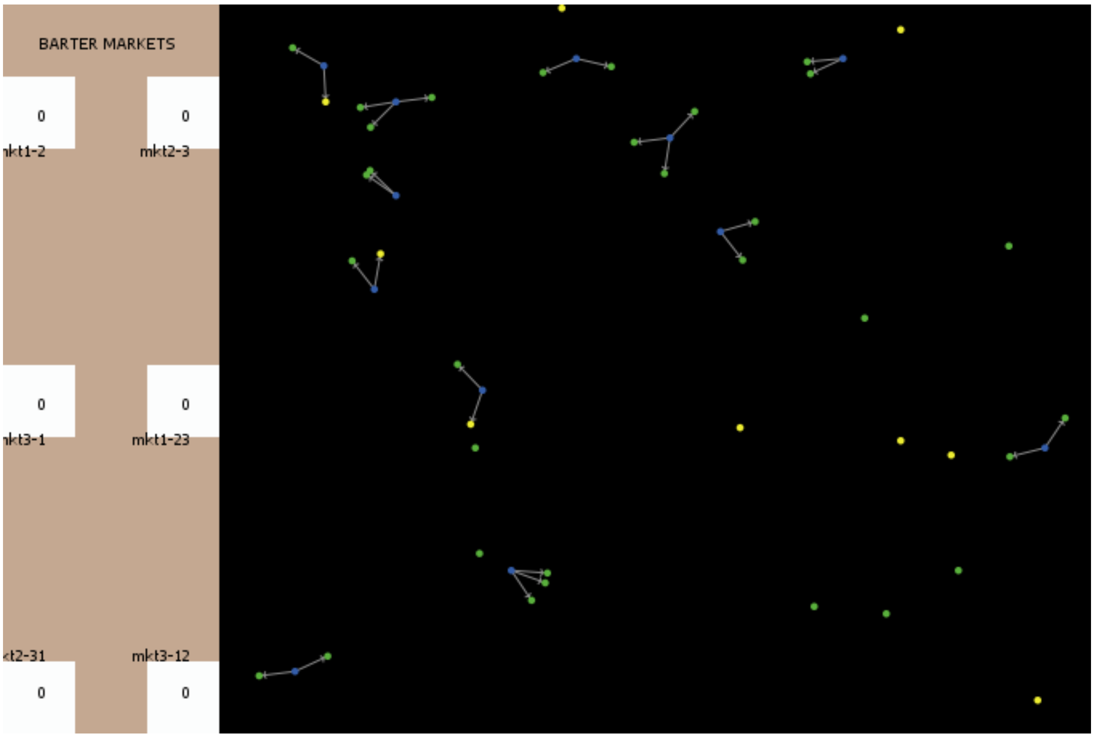


Fig. 9–Outlook of the world at the start of the first variation to the baseline simulation.

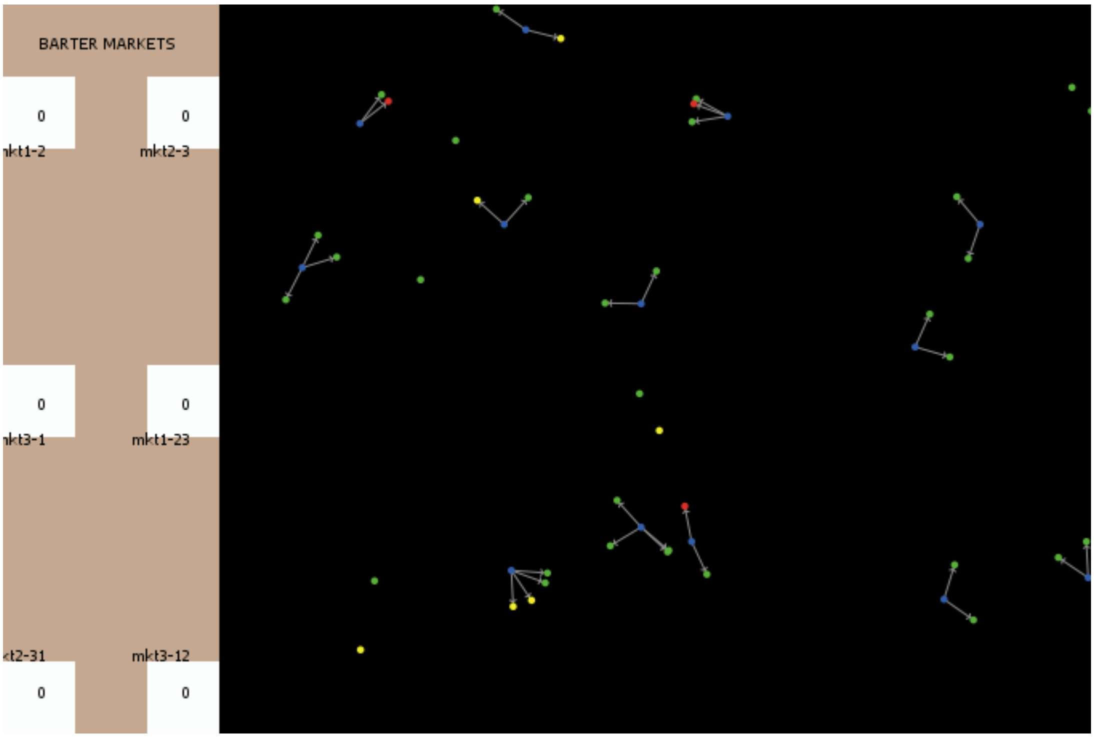


Fig. 10–Outlook of the world at the end of the first variation to the baseline simulation.

On the basis of these results, the overall size of the population appears to be at best a moderate predictor of the stability of monetary networks.

Variation 2: artificial increase in initial homogeneity of agents

To test whether a high degree of homogeneity and the achievement of a critical mass make a monetary network more resilient, the following experiment is run. The economy is created with 100 "controlled" agents, whose production is set to [10,10,10]. After very few ticks, all agents are expected to collapse onto a single monetary network: since production is at the top boundary for every agent, an agreement to insure a basket of [10,10,10] will be feasible and acceptable by everyone. This is indeed what is observed in the initial cycles, as shown in Figure 11.

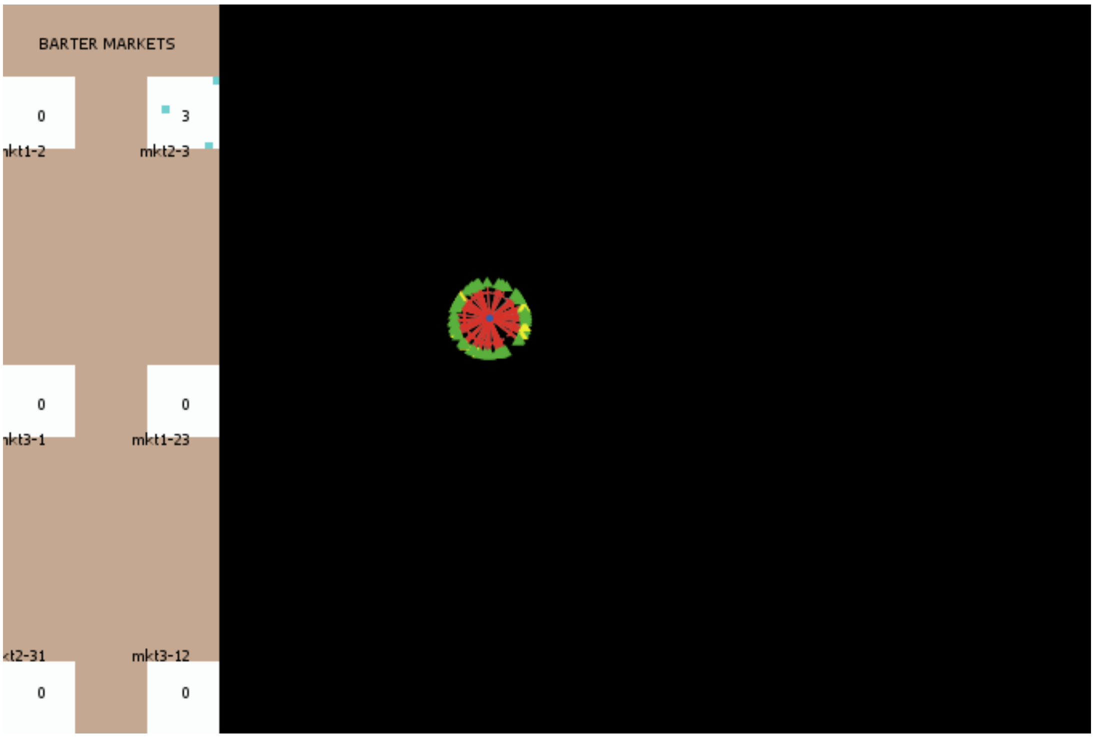
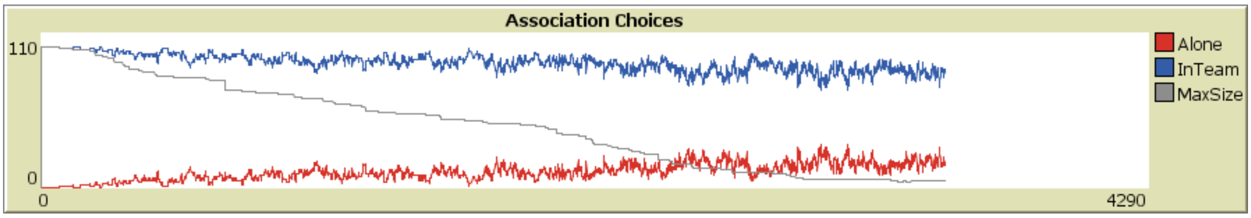


Fig. 11–Outlook of the world at the start of the second variation to the baseline simulation.

Interestingly, whilst the evolution of agents' production is uncertain, the monetary network appears to be very resilient over time, with only one agent leaving after 100 cycles. Over a longer period, however, disaggregation still takes place, with the initial network disappearing after ca. 3000 cycles (as shown in the plot below and in Figure 12).



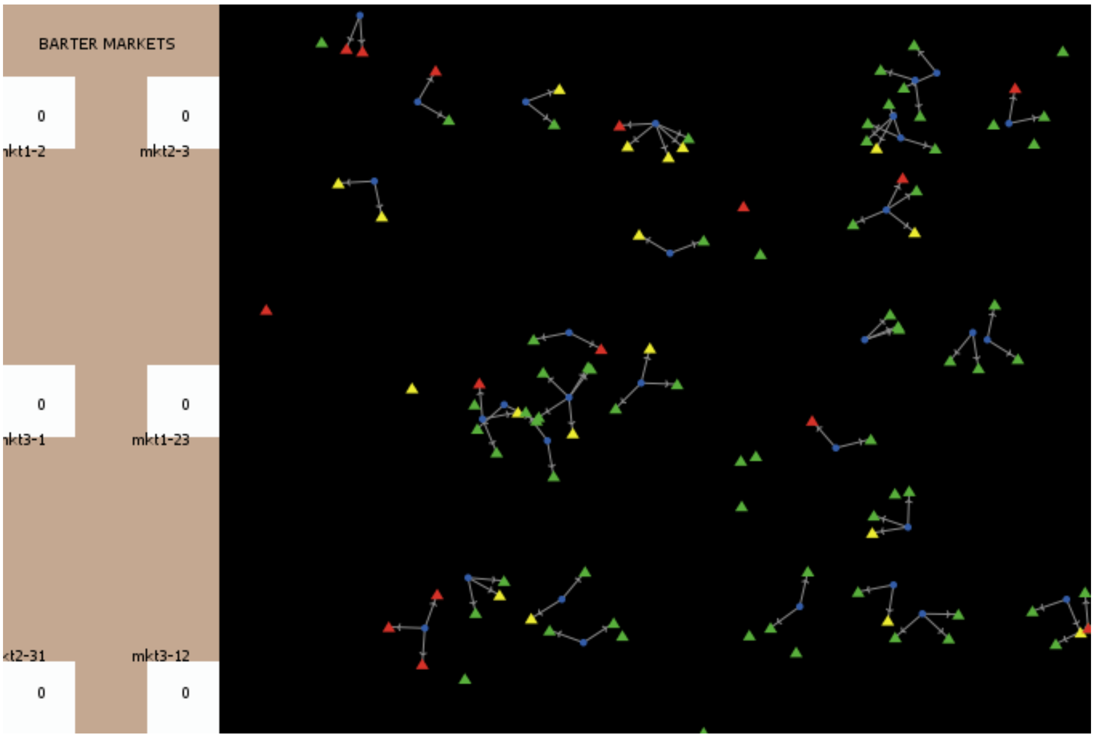
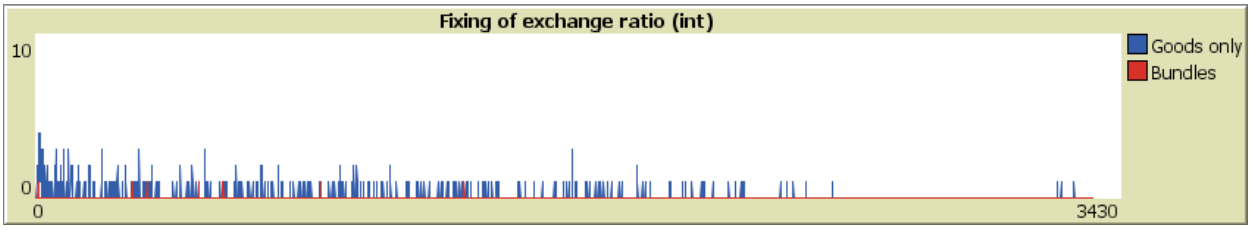
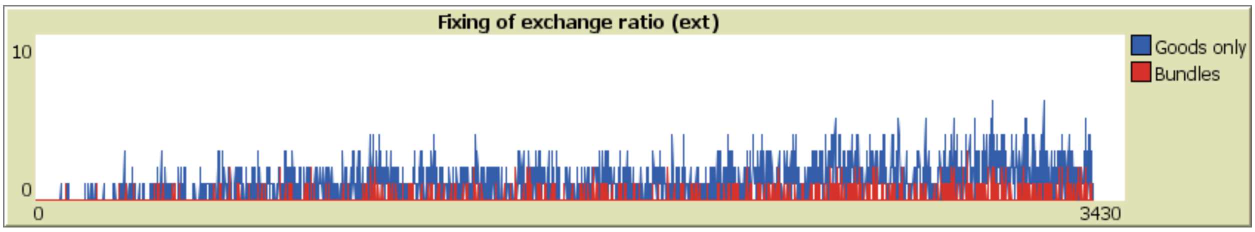


Fig. 12–Outlook of the world at the end of the second variation to the simulation.

Critical mass therefore appears to play an important role in the survival of a monetary network.

In addition, this experiment confirms the finding of the baseline simulation that barter transactions within a network do not involve bundles of goods. This is due to the fact that agents' endowments are partially smoothed by the internal transfers. Within a network, agents will therefore experience a lower necessity of entering "commodity vs bundle" transactions and will also not be able to find a counterparty for such transactions within the network (as other agents will also have "smoothed" endowments).





Concluding remarks and ideas for further research

In this paper, the creation, evolution, and destruction of monetary networks has been simulated to contribute to a more accurate characterization of money—whose nature remains the subject of extensive academic debate. Specifically, the monetary networks used in the simulation were *de facto* replications of communities where:

— Ruling elites tax the population as much as required not to break the social contract, ie. as much as required to guarantee to every individual a consumption basket considered acceptable by everyone (ie. considered *socially* acceptable). Rulers require individuals to pay taxes with money.

- Within this socially acceptable consumption basket, agents can engage in barter transactions to tailor this consumption basket to their preferences.
- When ruling elites fail to assure (through spending policies) a socially acceptable level of consumption of some good to some individual, they issue (and give such individual) money that can be used to purchase **other non-scarce** goods held by (i) other agents within the network, or (ii) other agents outside of the network. Given that all agents have to pay taxes with money, they will have incentives to give up their excess production for money.

Two surprising results emerge from the simulation:

- The achievement of a critical mass of members is as important as the initial homogeneity of members in predicting the survival chances of a monetary network.
- Within a network, transactions involving bundles of goods become scarcer, possibly facilitating the determination of bilateral exchange ratios in the economy.

This latter point could contribute to the development of a theory of **how a measure of value can develop from individual solutions to the inconveniences of barter** and **how decentralized barter exchanges based on individual subjective preferences produce a uniform standard of value**. As previously argued in the paper, **the emergence of monetary economies characterized by elements of mutual insurance reduces the need for and the possibility of exchanging bundles of goods**. In the absence of such complex transactions, identification of bilateral exchange ratios becomes possible. These bilateral exchange ratios are a prerequisite for the emergence of a uniform standard of value: such standard would make the bilateral exchange ratios consistent. **Without the elimination of transactions involving bundles, quantification of the relative pairwise scarcity of goods would not be possible and it would be arguably harder (if not impossible) to establish a uniform standard of value**. Thus, the insurance element of monetary networks becomes crucial to the possibility for money to act as a unit of account (one of the four main functions of money).

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