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ABSTRACT: Macroeconomic models are facing a crisis and their foundations need to be rethought. This report describes an agent based simulation model, which using the concepts and methods more familiar in micro economy, produces initial results that qualitatively correspond with several macroeconomic phenomena. These include robust growth and equilibrium characteristics, economic cycles, emergent money and complex supply chains. The model relies on private values and networked barter. Learning happens through rational negotiation and exchange of experiences, not through imitation.

KEYWORDS: Agent based social simulation, economic theory, value formation, emergence in economic models, emergent money in networked barter, Post Walrasian general equilibrium

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CONTENTS

1 INTRODUCTION

Models and measurements are the core of science. Most of the existing models in science are linear and their predictions can more or less easily be compared with measurements. When we encounter nonlinear phenomena, stochastic methods have commonly been used, but often their explanatory power is quite low and they do not give insight to detailed causal relations [1]. New methods need to be devised for complex systems when detailed models are important. Agent based simulation has often proven useful when studying nonlinear systems, or in other words, complex behavior. Agent based simulation models, which correspond well enough with physical reality and consist of credible component behaviors, can be considered scientifically valid [2]. Simulation is also useful as a tool, when the situations of interest cannot easily be recreated for measurement purposes in physical reality. Due to this reason, human behavior and especially organizational behavior are more and more often studied and modeled through the use of social simulations.

One area where great interest and great difficulty coincide is economic behavior. Current economic models are based on money both as the medium of exchange and as the measurement of value. Walrasian general equilibrium model is the main paradigm through which the various market phenomena are explained, the so called Law of Supply and Demand. This paradigm is facing increasing difficulties and solutions are being searched [3]. The impact of the so called network economy contains considerable amount of exchange and collaboration that is not easily converted to monetary terms. In networks, participants rarely share same information and social ties affect competition. Human behavior is diverting from the Homo Economicus model in many ways that are not easily handled through the existing paradigm [4][5].

Other principles such as Pareto efficiency have been questioned likewise. In the case of imperfect information, Pareto optimum is not reached [6]. Also it has been noticed that increases in production when calculated in terms of money do not necessarily increase the wellbeing of people. In addition to these problems, innovations have no natural place in equilibrium theories. There is no existing theory that even attempts to solve all these problems consistently.

This sums up the background of this work, which was started in 2001 and then described in some more detail in a seminar paper in 2004 in the context of organization theory and business strategy [7]. Due to other interests the work was not continued until 2008 when the author programmed the simulation and presented it to small audiences. Theoretical work has continued in 2010 and this is a technical paper describing the content and reasoning behind the 2008 simulation and some of its preliminary results.

A comprehensive literature review or comparison to existing theories is not included in this report. Many of the assumptions of the presented simulation model are grounded in well accepted theory but all references are not fully included in this paper and some others are at present based on intuition and require either founding on prior research or testing on different options. Due to the extensive realm of the simulation and its implications; this much larger body of work is mostly yet to be done.

It can be mentioned here however that no similar simulation is known to exist. The closest one that is found is briefly described later. It bears resemblance only in some parts. As complex simulations go, they cannot be divided in parts if their interaction gives rise to emergence. It is the whole sequence of events you need to simulate to gain insight in the emergent phenomena. Thus it is believed that this work contains important original contributions that can already be appreciated in spite of an apparent need for further clarification and background research.

2 BASIC PRINCIPLES

When we attempt to model economy that includes competition and innovation and social networks, we need to start from the foundations. Selection of the agents, and their parameters and allowed actions is crucial. The proposed model aims simultaneously at parsimony and wide explanatory power. Basic assumptions are generally described in this introduction. Further details are given in each following chapter before results and implementation issues are described.

In theory, all exchanges can be considered as barter. Each agent sees some private value for utilities and any medium used specially for exchange purposes can emerge from utilities used in barter, thus there is no need for a separate concept of money. No consideration is given to synchronicity or bookkeeping of barter except to notice that all bookkeeping is private and based on private expectations and values. Any labor required for bookkeeping or barter is considered as part of the efficiency of exchange that is included in the model. Assumptions are based on Transaction Cost Economy [8].

Individuals are selected as agents. When we consider social networks and their effects on economy, we must see that individuals both make decisions, have needs and social relations. There has been criticism against many models of social networks that use the concept of trust between firms [9]. The concept of firms or clans as groupings of individual agents is planned for but not yet implemented in the current simulation. In the plan, it is considered an attribute of an agent and it lowers transaction costs between members of the hierarchy or adhocracy depending on the type of firm. In the realm of Organization Theory, firm is either considered as an agreement between individuals to further their own agenda (Institutional Theories) or a grouping of people to work more efficiently in collaboration (Knowledge Based View). Both phenomena are emergent in this model through network clustering and further study is required to see if there is need for additional concepts to support emergence of economic organizations and especially those where decisions are hierarchically made.

Social networks and their implications to firms and economy have attracted growing interest [10]. Social networks are formed between individuals, and they also handle all economic transactions and make all decisions in practice. Individuals only know a limited number of other people well enough to initiate and do business with them in such a manner that can be said to lower transaction cost compared to any random transaction. A maximum of circa 150 well known acquaintances is commonly referred to in psychology. At present, all agents have similar sized social networks. The networks are directed and an agent may belong to some other agent's network without the other agent belonging to his network. The network of acquainted agents is not static. New candidates to a network are searched randomly. In the future, this should be an area of further study. Scale free networks may have important implications to exchange, but in most cases it is not social ties but products that are widely known and that effect is already supported through capability to retail any product.

In the proposed model there is no concept of distance between agents, but each dyadic transaction becomes easier when repeated. This includes all learning and development in logistic procedures. Considering both history and contemporary ages, it can well be seen that individuals both produce and sell their services and products and firms have only a partial role in the exchange. Thus models that concentrate on firms and consumers and workers cannot penetrate very deeply into the phenomena of exchange.

We assume that human beings have rather similar needs to one another. Some of these needs require more effort and some less effort to fulfill. As we talk about fulfilling needs, we should understand that most of the needs can be fulfilled in various ways that are not directly comparable as products or services. We talk generally about $utility_i$ for fulfilling the corresponding $need_i$. As any modeled $utility_i$ can be implemented through various products or services, there is no direct comparison of prices as such, but an agent satisfies his needs as he best sees fit and we do not differentiate the products in any way except classifying them as $utilities_i$ for fulfilling $need_i$. This assumption is very realistic but it also causes problems for practical calculations in the real economy. As this paper describes a theoretical model, no attempt is done to analyze what these needs might be in practice. The needs are not fixed in their volume even though they are considered to have a minimum required level. Price elasticity of demand is included in the model and actually without price elasticity, economic growth may be difficult to model in any realistic way. Price elasticity of demand in the proposed model can be interpreted in many ways, either we consume more of some utility that satisfies our need or satisfy our need of that utility with some product or service of higher quality than before or in a more wasteful way.

As a metaphor of the starting point of the simulation, we select the general lifestyle of hunter gatherers, where each adult individual can support her own needs without any need for barter. Initially each agent is able to provide for her own needs and has a small stock of everything. Each agent has a small and random inborn capability for slightly increased efficiency in fulfilling some of the needs. This corresponds to human beings inborn traits or educational differences. After fulfilling one's own needs, an agent may use the excess time to producing excess for own stock or for bartering purposes.

When two agents are acquainted, they compare their options and barter if both see gain from the exchange through each agent's private value systems. Continued production over one's own need leads to specialization. Adam Smith says in his Wealth of Nations: "The greatest improvement in the productive powers of labour, and the greater part of the skill, dexterity, and judgment with which it is any where directed, or applied, seem to have been the effects of the division of labour." When an agent produces some utility above his own requirements, his efficiency in that kind of production is increased. Both productions related learning and innovation are included and not separated from each other.

The private value system is based on the effort of fulfilling each need. Adam Smith was quite clear: “Labour alone, therefore, never varying in its own value, is alone the ultimate and real standard by which the value of all commodities can at all times and places be estimated and compared. It is their real price; money is their nominal price only.” Adam Smith saw money as a convenient way of comparing prices and exchange values, but noticed that the real price varies from person to person, place to place and time to time even though the nominal price would be the same [11]. Thus it is reasonable for us to talk about the price or value of money itself, and that is one of the results of this study.

Max Weber writes: “Substantive rationality cannot be measured in terms of formal calculation alone, but also involves a relation to absolute values or to the content of the particular given ends to which it is oriented. [...] A system of accounting in kind would have to set up indices of the value of various significant resources which would play the role of accounting prices of modern business. [...] In principle, as an observable fact, a monetary unit has a substantive value only in relation to particular kinds of goods and only for each separate individual as his own valuation on the basis of marginal utility of money for him, which will vary with his income.” [12] Although Max Weber considered calculations in kind to be impractical, this simulation model is based on those and calculations are done separately for each individual. And whatever money (media of exchange) there is, it is not defined separately but it is emergent, thus having private value for each agent similarly to other utilities, and like metal money in historical ages, exchange media can be produced by any agent.

It is clear that any realistic simulation of economy needs to take into account the two different ways of economic decisions Max Weber pointed out. When one satisfies one’s own needs, or when one invests in utilities for maximizing profit in exchange, the heuristics differ. If we expect to profit from exchange, this is taken into account in stock limits and private values that affect production and exchange behavior. Also it must be noted that when you gain profit from barter and use the newly acquired utility as a payment for another exchange, you may see the value very differently from what labor it would require if you produced it yourself. Thus an agent may end up paying more for some utilities than his own production cost, if his available production time pays better when used elsewhere.

There is ample proof that we have an inborn trait for fairness [13]. Studies show that an agreement often fails if profit is not equally divided between parties, thus 50/50 deals should be typical. In each exchange, the mutual gain in private values is calculated and such “negotiated” exchange rate is selected that yields highest mutual gain that is then divided for both according to their private valuations. All potential trading partners are evaluated before committing to an exchange, and the most profitable ones are selected. Successful and unsuccessful transactions affect an agent’s private values. It is assumed that a realistic randomized process would not lead to any considerable difference in results compared to this approach, which is faster to simulate, where realistic averages are used.

No exchange is practical without agents producing surplus and carrying stock or corresponding investment in production capacity. Surplus utilities are produced for one's own future needs or to be used in exchange for other utilities. Useful stock size is estimated based on the agent's own basic need, elasticity of demand accounted for. If an agent has recent experience that a utility is useful in exchange, this increases stock limit. Stock value is optimized through exchange with networked friends if an agent has enough surpluses to experience leisure time and can consider other issues besides just satisfying one's own basic needs. Through these features, the agents can act in all common roles of a supply chain.

As an agent bases his private values and stock sizes on expected usefulness, these values are updated continuously when supply or demand changes. It is clear that increase in demand will generally lead to larger potential stock and profit in exchange value will increase valuation. Naturally when demand falls lower, maximum stock is lowered and if the situation continues, overflow of stock will lead to decrease in value and later to slow spoiling of stock. Thus an agent learns values through actual own experience and does not directly copy or imitate values from other agent's private value systems. This allows agents to operate in different points of the value chain and different network environments. Producer's own private values for utilities are very different from those of consumers.

As agents expect to profit from exchanges, they need to have separate threshold values when giving or receiving each utility. All profit calculations are based on these values and the unit of value is based on time, but it should be understood that the connection to actual production time is modified strongly through experiences in exchange.

Unlike many other economic models, this proposed model does not even aim to result in Pareto efficiency even though the model, through each agent's selfish pursuit does lead to well behaved economic growth. It is understood that the exchanges have a positive sum, but due to lacking information, they may still have negative effect to one of the parties. It is also that in the absence of perfect information or complete markets, outcomes will generically be Pareto inefficient (the Greenwald-Stiglitz theorem).

2.1 Important prior work in agent based simulation models

There are many important simulations but macroeconomic agent based models have only been developed very recently. Only the most extensive of these models is mentioned here.

Herbert Gintis is a well known critic of the Walrasian general equilibrium theory. In "The Dynamics of General Equilibrium", he claims to present the first general, highly decentralised, agent-based model of the dynamics of general equilibrium [14]. His model includes firms as producers and individuals as workers and consumers, the concept of money and exchange using private values. Firms receive financing and consumers have individual utility functions. Gintis has done a thorough literature review and concludes his model to be the most extensive one. He points out further work i.e. saying his model lacks inter-industry trade and retail, has very simple asset heterogeneity, no structure to the firms, and no costs associated to the transactions [14].

In spite of evident similarities, the model described in this paper differs greatly from that of Herbert Gintis. Firms are emergent through network clustering, utility functions are basically similar from agent to agent, and separate markets exist only through agents different networks. Production and work is not separated conceptually. What money there is, is also emergent. Wholesale trading and retail is supported and individuals specialize and change their specialties if demand for their products weakens. Learning happens through negotiation process, but direct imitation only takes place in consumption patterns.

The proposed model in this paper has not yet been analyzed nearly as thoroughly for equilibrium characteristics as that of Herbert Gintis. A thorough comparison of the results should be done in those areas where the results can be compared to each other. However it must be said that private values of utilities are not easily comparable when it is as easy to talk about the private value of money as of the value of any other utility. When the supply chain grows longer through increasing specialization, the purchase value of some specific utility for the producer or wholesaler is quite different from the purchase value of the same utility for the consumer. The most meaningful measurements are those of average production and utility levels, average deviation from the utility level, transaction costs and the general production and exchange levels of common and rare utilities in the simulation. It is clear from the results that some similarities exist and several notable new phenomena can be seen that have good general correspondence to both microeconomics and macroeconomics.

3 OVERALL STRUCTURE OF THE SIMULATION MODEL

The most important concepts are agent, network, need, utility, production, stock, exchange, transparency, timeslot, leisure time, purchase price and sales price. An overview to each is given here briefly before entering the more detailed description of the simulation algorithm.

- An agent represents an individual person, who has needs and capabilities to produce and stock utilities and exchange them with other agents in his network.
- A network is the list of an agent's acquaintances. Each agent can have a limited number of other agents in his network. An agent can initiate exchange only with acquaintances. A passive acquaintance can be replaced by another agent.
- A need describes how many corresponding utilities an agent requires in each simulation cycle to be satisfied. There are n different needs and correspondingly n different utilities. The needs are not equal in size.
- A utility satisfies a need. Utilities can be produced or gained through exchange.

- Any individual can produce any utility for satisfying their own need. An agent talented in some utility can produce that utility for stock. If an agent produces some utility in higher volume than their own need, their experience grows and they are able to produce the utility more efficiently.
- Stock is where an agent stores any unused surplus of a utility. Stock can be used to satisfy a need or used in exchange with another agent for another utility. Stock size is limited to an agents expected near term usage.
- Exchange is useful when an agent has surplus of some utility in stock and another agent in his network has some other utility in stock and each agent values more that, which the other agent has. All exchange options are evaluated each cycle.
- Transparency from an agent to receiving some utility from another agent in exchange determines transaction cost. Transaction cost wastes part of the received utility. Transparency is increased through experience.
- Timeslot is how long it takes initially to produce one utility of any kind. An agent has enough timeslots to produce all utilities required to satisfy their all needs. When efficiency grows, timeslots cannot be all used and this is considered leisure time.
- Leisure time is a sign of wealth and needs increase.
- Purchase price is a private value an agent has for a utility. It shows how valuable a utility we are at maximum willing to hand out in exchange for this utility. Initially purchase price is 1. When deciding what to produce, own production of initial efficiency 1 is comparable to purchase price 1. Thus price units may be interpreted to equal timeslots.
- Sales price is a private value an agent has for a utility. It shows how valuable a utility we at minimum require to give out this utility. In exchange situations, only each agent's private sales price / purchase price -ratios affect the negotiation.

If we consider the simulation model from the viewpoint of game theory, the simulated game is Bayesian as each agent has only imperfect information on the situation. Agents have knowledge only from their own network, which gains new members in a random manner. From their network, each agent only gets partial information from private values and availability of products for exchange.

Each dyadic exchange is calculated using an average transaction cost. In principle dyadic exchanges would be better implemented as Bayesian too, but due to efficiency reasons, success of each transaction is averaged to a deterministic loss that depends on several factors whose sum can be calculated ex ante. Reliance on the averages leads to faster learning but besides the resulting effect leading to greater stability; it should not affect other equilibrium characteristics. Using random results in transactions would slow the simulation down possibly several orders of magnitude and make the whole simulation practically impossible. The randomness in talents and networks is considered to provide enough variability to the initial situation.

The simulation is run in stepwise cycles. To avoid favoring any agent, each agent is evaluated fully in each cycle. The evaluation order mostly has a satisfactory resemblance to intuitive order of things. Some other realistic options for ordering the phases may exist, but this order is selected for efficiency reasons and as the process is cyclical, difference in results if other realistic options were used is believed to be small. Other options should be considered and results compared to ensure robustness however.

Each agent, each cycle:

1. The needs and timeslot counter are reinstated.

2. Each $need_i$ is satisfied from previous surplus $stock_i$ if such exists.

3. For remaining needs, each $need_i$ is considered separately and all networked friends are checked for surplus and exchange possibility. The cheapest source for each remaining $need_i$ is selected and exchange committed if considered profitable. Heuristics for friendship acquisition, private value system and profit calculation are explained later.

4. For remaining needs, each still unsatisfied $need_i$ is satisfied by producing corresponding $utility_i$ while available timeslots are reduced correspondingly.

5. Remaining timeslots are utilized for producing excess to stock. Heuristics for selecting the most suitable $utility_i$ for production is explained later. There is a possibility that not all timeslots can be used as heuristics limits the size of $stock_i$ that is considered useful.

6. If leisure time exists, all needs are temporarily increased in proportion to the amount of leisure time available and price elasticity is taken into account. Steps 2-5 are repeated and each $surplus_i$ is checked if it could be exchanged for profit with any networked friendk. The most profitable exchange opportunities are selected. Heuristics is described later.

7. Private values, relationships and experience are updated to reflect new transactions.

3.1 Parameters of each agent

There are n individual agents, test data is produced with $n = 3,000$.

Each individual $agent_k$ has m different needs and m corresponding capabilities to produce utilities to satisfy the corresponding needs. The total number of needs for each individual agent is m, thus each agent has all needs. At present simulations m is set at 30.

For each $agent_k$ the production of $utility_j$ to satisfy $need_j$ in the example runs requires j^2 timeslots per each cycle without any gain in experiencej. Thus i.e. the individual $need_1$ requires 1 production units of $utility_1$ and the $need_{30}$ requires 900 production units of $utility_{30}$ during each cycle. This means that needs are ordered by the default number of timeslots required to satisfy them. All basic needs are considered of equal importance so that each $need_i$ must be satisfied. Basically then, this is a question of grouping the needs based on the effort required to satisfy them and is suggested to be mainly a definition and not an assumption. The reason for having the group sizes different is to increase realism and to let us see if utilities that allow for great specialization behave differently from utilities that require a large share of effort to produce.

Production $experience_i$ to satisfy a $need_i$ is initially set at 1 for all needs. Each individual agent is then given random needs-related talents. Number of talents is 50% of all needs in test simulation. For each $talent_i$, production $experience_i$, for $need_i$ is increased modestly, 50% in test simulation. Each individual produces one production $unit_i$ per one timeslot multiplied by production $experience_i$. Each individual has timeslots enough to provide for all his needs with no experience. Thus each $talent_i$ provides for potential small initial $surplus_i$. This assumption is very realistic.

3.2 Social network of the agents and dyadic parameters

During each cycle, each agent evaluates their friendship network. Contacts are ordered by recent transaction activity and new contacts replace most passive contacts with smallest weighed index of transactions. Index is calculated by reducing the index each round by a fixed percentage. Thus oldest transactions have least weigh. A new contact is selected randomly. When an exchange is initiated from another agent, this agent is automatically evaluated as a potential friend. However friendship networks are basically one sided and each agent evaluates independently who remains in their network. Each dyadic friendship relation includes information on the frequency of transactions, but also information on what kinds of transactions have taken place. This information is used to determine potential efficiency of each particular kind of transaction between the two agents. Test data is produced with a maximum network of 100 other agents for each $agent_k$.

3.3 Parameters of consumption

Initially the size of each $need_i = i^2$. Each need can be satisfied either from stock, through exchange or by producing it. There are enough timeslots to satisfy all needs without any stock or exchange. As specialization increases production experience, the surplus production is stored for future needs or exchange. There are limits to what an $agent_i$ sees practical to produce and thus it is possible to end up with unused timeslots.

If all timeslots cannot be used, it is read as a sign of high income and all needs are increased by multiplying them first with $needsincrement = maxtime/(maxtime - timeremaining)$. The change in $needsincrement$ is then limited in each cycle to better correspond with general human behavior of some slowness in changing routines. This increase in needs corresponds to the fact that people with higher income tend to satisfy their needs with more utilities or higher quality utilities. The increase in needs is not linear but after basic needs are fulfilled, the added needs are modified with taking price elasticity into account. Those needs are increase more where production cost is lower than average and the other needs are reduced correspondingly. As excess demand is shown to be culturally modified, price elasticity is calculated based on average production cost and not on private values. Thus the price elasticity may contain imitation and marketing effects, but none of these are assumed.

It should also be noted again that the needs and corresponding utilities described here do not correspond to particular products or services directly.

3.4 Parameters of production

Initially the production of any single utility item requires one timeslot. If an agent is experienced in producing a particular $utility_i$, he uses less time for that production. In example simulation, the $talent_i$ raises efficiency initially by 50%. Talents are random. In test simulation each agent is gifted in c. 20% probability in producing each particular $utility_i$. This probability is not expected to affect the results in any considerable way unless extremely low or high probabilities are used. Surplus production to $stock_i$ is only performed at present where the $agent_k$ has $talent_i$. Efficiency is increased also through $experience_i$ in production and if it surpasses the effect of $talent_i$, only $experience_i$ has an effect.

$Stock_i$ is also used to store utilities received in exchange if they are not directly consumed to satisfy needs. Maximum $stock_i$ for each $utility_i$ is calculated separately, and each agent has private estimate on how much it is practical to store each $utility_i$. This estimate is based on how much an $agent_k$ needs the $utility_i$ for consumption and how much has been handed out in exchange for other utilities or sold in other words.

Recent $production_i$ is calculated by adding current cycle production to discounted previous recent $production_i$. Recent sales and purchases that an agent gives and receives in exchange are calculated in a similar way.

Maximum $stock_i$ of any $utility_i$ is calculated as a sum of recent $sales_i$ and basic $consumption_i$ of a few cycles of the $utility_i$, elasticity of demand taken into account. Both timeframes are arbitrary parameters that are not believed to have any considerable qualitative effect on the results. If sales go down, maximum $stock_i$ limit may be exceeded and excess $stock_i$ is partially spoiled in each cycle.

Product $experience_i$ is calculated as square root of agent's recent production per the sum of needs during the same time. Thus if the agent produces for himself only, efficiency is one, but if an agent produces four times his own need, efficiency is doubled. Time consumed for each $production_i$ satisfying remaining $need_i$ is calculated as $need_i/experience_i$. This formula for adding efficiency is arbitrary. As long as efficiency can be multiplied through experience, the specific formula is not expected to change the results in qualitative sense, and initial tests seem to confirm this but no extensive tests are done. Each $utility_i$ for surplus $production_i$ is selected from those that have room in $stock_i$ and to whose production the agent has $talent_i$. The highest available production $index_i$ is selected and the corresponding $utility_i$ is produced until timeslots are out or $stock_i$ is full. Production $index_i$ is calculated based on $efficiency_i$ and realized private sales $price_i$. It is clear that both should be considered. Efficiency takes into account what we are used to do and will do when we follow routines. High sales $price_i$ is a clear motive, too. Sales volume is already taken into account in the size of stock. Several possible heuristics exist that should be studied further. The most intuitive have been selected for current simulation.

3.5 Parameters and heuristics for barter

For each $agent_k$, each unsatisfied $need_i$ or any $utility_i$ that can be fitted in $stock_i$, each $friend_l$ who has a $surplus_i$ of that particular $utility_i$ is checked. For each proposing $agent_k$, exchange profit is calculated for each possible exchange where $agent_k$ has $surplus_j$ and $friend_l$ has no $surplus_j$ or room for more $stock_j$. Calculation is based on private value ratios of both parties. The most favorable exchange is selected to satisfy each need.

$Exchangeindex_{(ki<>lj)}$ should be positive in order for the exchange to have a sum positive value and it is calculated from private values as follows: $friend_l$ purchase $price_k$ of proposed gift per $friend_l$ sales $price_j$ of required $utility_j$ times inefficiency of transaction minus $agent_k$ sales $price_i$ of the gift per $agent_k$ purchase $price_j$ of the $utility_j$. In other words, the private value of what both get in exchange (multiplied with each other) should be greater than what they both give (multiplied with each other) transaction inefficiency included. It should be noted here that we do not assume that both parties of the exchange will actually win, but we assume only that the expected sum result of the exchange is positive. This generally seems to hold true for almost all trade including regulated trade.

Transaction cost is taken into account as transaction efficiency factor indicating transparency and it is calculated for all dyadic and market transactions based on agents experience and dyadic history. Transparency is directed and it is always calculated from the receiving direction and lacking transparency is calculated as waste and decreases the yield of $utility_i$ at the receiving end without affecting the source.

When the highest exchange index is found and exchange is committed, the maximum number of utilities is exchanged limited by agents need or stock limit and maximum stock limit of the friend and availability of the utility in friends stock. Both see different exchange ratio based on their private values of what they get and give. Exchange ratio is calculated as the average of the differing opinions and can be considered as the most probable result. Thus exchange ratio is friends purchase price of proposed gift per friend's sales price of required utility times inefficiency of transaction plus agents sales price of the gift per agent's purchase price of the utility times inefficiency of transaction per two.

3.6 Value formation, sales and purchase price thresholds

When each $agent_k$ ends their cycle, for each $utility_j$ both an expected minimum sales $price_j$ and expected maximum purchase $price_j$ are calculated. Production cost of each $utility_j$ is $1/efficiency_j$ and basically this shows how much time is used to produce one utility. Unit of calculation for the private threshold values, minimum sales price and maximum purchase price are also based on time used and are initially same as production cost and are changed according to the following somewhat intuitive rules:

For maximum purchase price of each $utility_i$ we have three different situations:

1. When stock of the $utility_i$ is small or none, maximum purchase $price_i$ may be increased unless higher than both production $cost_i$ and minimum sales $price_i$. Purchase $price_i$ may exceed production $cost_i$ if recent $sales_i$ exceed recent $production_i$.

2. When stock of the $utility_i$ is on the normal level, maximum purchase $price_i$ is checked. It should not be above minimum sales $price_i$, and if sales are small, it should not be higher than production $cost_i$ and not too much smaller either if there is production going on.

3. When there is a large $stock_i$ of the $utility_i$, we lower the maximum purchase $price_i$ and check that it is below production $cost_i$ if $sales_i$ are small.

For minimum sales $price_i$ we have similarly three situations:

1. When stock of the $utility_i$ is small or none and $sales_i$ have been high, we raise minimum sales $price_i$ to average recent sales $price_i$. If sales $price_i$ is below both production $cost_i$ and purchase $price_i$, we raise it to the level of purchase $price_i$ if purchase $volume_i$ is considerable and otherwise to production $cost_i$.

2. When stock of the $utility_i$ is on the normal level and $sales_i$ are low, we set minimum sales $price_i$ to production $cost_i$.

3. When there is a large stock of the $utility_i$ we discount. If there have been no $sales_i$, we go directly to production $cost_i$ and discount further if the situation remains.

There have been some experiments on these rules and any changes that have affected end results considerably have been very unrealistic. Extensive testing has not been done.

3.7 Transaction inefficiencies and waste

There are two kinds of $waste_i$. When an $agent_k$ has too large $stock_i$, the excess $stock_i$ spoils partially on each cycle. The $stock_i$ may become too large when expected sales $volume_i$ is not realized and maximum stock $limit_i$ is reduced below the actual $stock_i$ size. This event is very realistic and happens to most utilities through physical spoiling or when utilities get out of fashion

The other kind of $waste_i$ is linked to exchange situations. All kinds of search costs, mistakes, negotiation costs, lacking specific assets and various other transaction costs are represented by lack of transparency. Transparency is measured as a directed parameter separately from each agent to every friend and for all utilities received in exchange. When $agent_k$ gives $utility_i$ to

$agent_l$ and receives $utility_j$ as payment, transparency of $agent_k$ to $agent_l$ for $utility_j$ is used for calculating waste of $utility_j$ in the exchange and transparency of $agent_l$ to $agent_k$ for $utility_i$ is used to calculate waste of $utility_i$ in the same exchange. This waste is removed in the exchange and thus is given but not received.

Transparency from $agent_i$ to $agent_l$ for receiving $utility_i$ is increased through all recent transactions between $agent_k$ and $agent_l$, $agent_k$ being talented and experienced in $utility_i$ and $agent_k$ having received $utility_i$ previously from $agent_l$. Initial testing seems to show that the emphasis of these effects can vary considerably without affecting the quality of the end results in any major way. But simultaneously it should be mentioned that these learning based efficiencies help in creating stabile structures that help in adding to income differences. The effects should be tested further.

Through this concept of waste it is meaningful to talk separately of increase in production and increase in consumption or satisfying the needs.

4 INITIAL RESULTS

All the agents satisfy initially all their needs with their own production. Some surplus is produced due to giftedness. As friendship networks are formed and exchange possibilities are studied, some exchange takes place between friends, but mostly to satisfy both exchanging parties own needs. Transaction costs and stock spoils remain low. In the earliest phases largest efficiency gain and most utilities being exchanged are those with largest need. This resembles early markets full of commodities.

As all agents are gifted in producing several different utilities, some agents shift their preferred production to more rare utilities when their friendship network grows and the number of utilities being exchanged grows. Production efficiency slowly increases in smaller volume utilities and they start to be traded. The further the simulation goes, the more rare products enter the exchange. Simultaneously with specialization, also supply chains grow and production efficiency grows faster in the rare end of utilities.

In the later stages, very few, depending on the number of needs and agents, possibly even one producer dominates the whole market for each of the rarest utilities but the utilities pass through several wholesalers and distributors before being consumed. In the supply chain, there exists some instability as agents grow their stock when they see growing demand. This causes fluctuations, and sometimes even boom bust cycles in the production of some utilities.

Price elasticity starts to affect development when most needs are satisfied through exchange and production efficiency has risen high enough. Price elasticity affects rarest utilities more than others as specialization in highest there and thus also production efficiency. The end result is rather realistic, consumption of luxury or convenience items grow fastest when people become wealthy.

From detailed study of the events in the simulation one sees a multitude of lifelike phenomena whose statistics is presently unavailable due to the limitations of the simulation software. As private values change, agents end up with

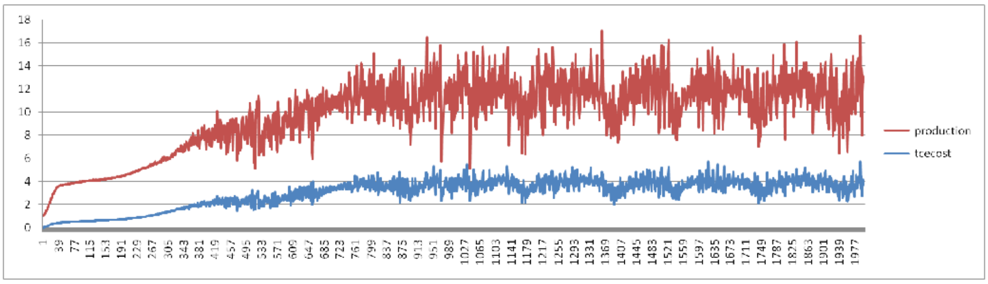

Figure 1: Production growth is initially fast as direct friends utilize their exchange possibilities. Transaction cost grows then considerably in spite of increasing transparency in dyadic transactions. This is due to lengthening of supply chains and increasing use of exchange media. Overall complexity of exchange grows. Economic cycles are clear. Both production volume and transaction costs are measured in total number of produced units per total usable timeslots. It must be remembered that results vary greatly across utilities.

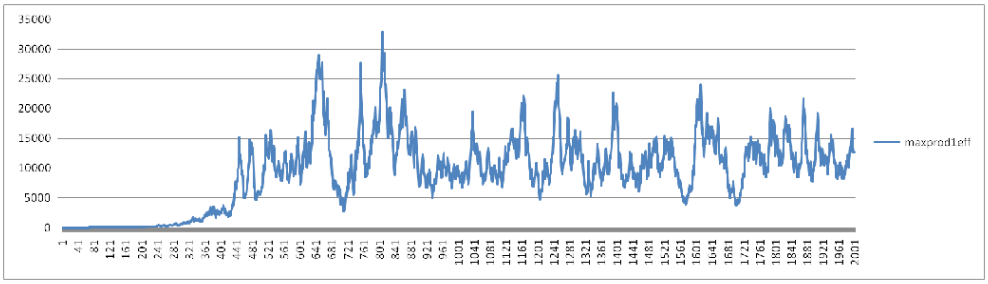

Figure 2: In the rarest product, maximum produced number of that utility per corresponding average need shows that the largest producer supplies more than the total need for the whole agent population and has practically monopolized the market. Due to possible competition and fluctuation of stock sizes the production volume experiences constant change. Excess production is consumed to transaction costs and waste in the supply chain. This is expected as the rarest product is often used as exchange media.

the need to devaluate stock, causing trouble for agents that have made mistaken assumptions and sometimes causing crisis for the whole supply chain and often also spoiling of stock. This also causes unemployment like behavior and the need for agents to fall back to producing for their own needs in spite of inefficiency, and the attempts to better the situation by specializing to new production lines. These fluctuations seem to happen often for the rarest one or two utilities that are generally stocked in later phases and used for exchange in numbers that greatly exceed their consumption. The rarest utilities seem to fulfill the criteria of exchange media and can be thought of as rare metal based free money. Fluctuations in these utilities seem to have several resemblances in the simulation model to economic cycles.

After several hundred cycles the total production growth has slowed down and the system can be considered to reach equilibrium. In the test run the simulation is continued for 2000 rounds to show that cyclical behavior is a

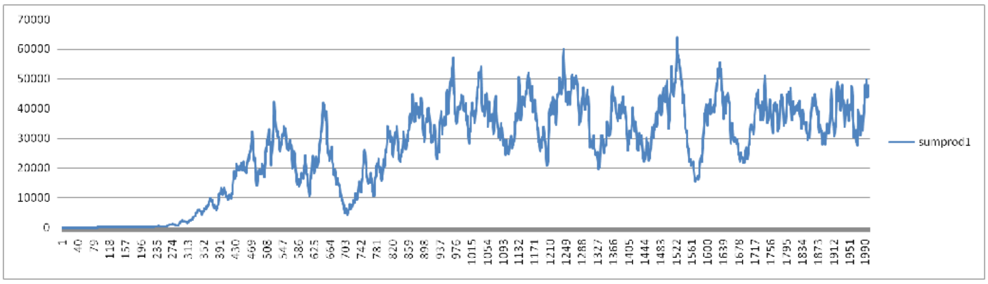

Figure 3: The total production in units of the rarest utility per population size. These figures do not correct for price elasticity or needs increase but show the absolute production figures.

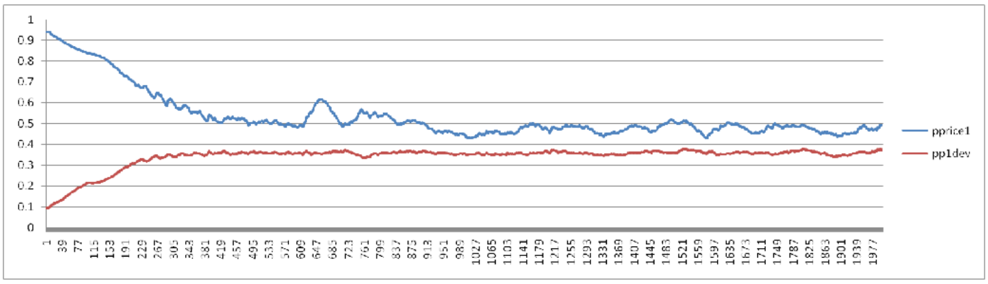

Figure 4: When oligopoly or monopoly situation is reached, private purchase price of money remains generally very high compared to the average production cost. The average deviation of purchase price of utility 1 is also very high due to long supply chain.

property of the equilibrium. It is clear from prior experiments that a higher number of needs and agents, faster growth would continue longer. After this phase, structures get more rigid, producers of rare utilities are relatively safe from competition due to learning curve of production and their customer network.

5 IMPLEMENTATION ISSUES

The software is written in C-language using integer math in most algorithms. The implementation method was selected as the algorithm is rather time consuming even when all variables are stored in ram memory. The program size is c. 1300 lines of including debug and data collection code. Due to using integer math, many numbers are ten folded and small deviations are rounded off. Some algorithmic decisions are made on efficiency reasons where the decisions are not considered to affect the results. As the database evolves almost completely on each cycle and is several gigabytes in size, all history data needs to be condensed and saved separately for later analysis. Currently the simulation displays both consolidated data and selected test agents behavior each cycle. Hundreds of hours has been spent studying behavior and decision making of the agents. On a regular PC, test run takes few hours for 3000 agents, each with a network of X friends and Y needs.

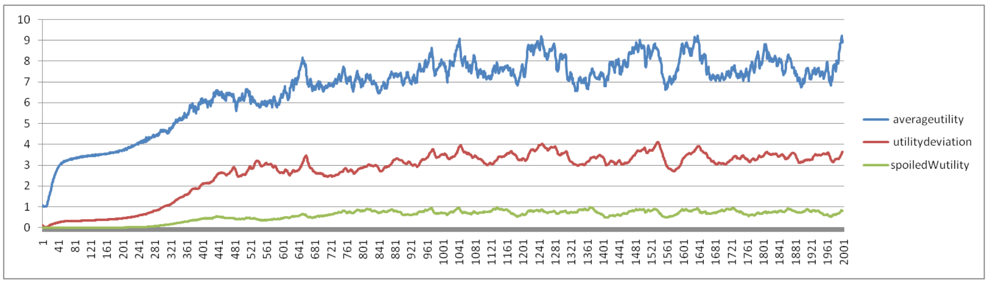

Figure 5: Average utility level measures in how many multiples the needs can be satisfied by agents during each cycle. Like total production, this measurement of “living standard” displays clear economic cycles. Spoiled utilities would be high if measured in unit numbers but in this figure they are converted to time units, and spoils represent less than 10% of the total time spent in production.

6 SUMMARY

This report has pointed out some of the grave weaknesses our existing macroeconomic paradigm contains. New paradigm needs to be sought out that includes dynamic properties in complex environment. Agent based simulations are the proposed answer. As our economy consists of individual human beings, who often freely select whether they work for someone else to obtain media for exchange and then buy what they need or directly provide for themselves, and as many schools of thought model firms as contracts between people, the fundamentals of economy should be based on exchange between individuals and not on exchange between individuals and firms. As social ties are important, this exchange should take social ties into account. We have also shown that money does not have same value for everyone and individuals have a high number of activities outside monetary economy. Thus a foundation should be sought where private values are not based on money, and income can be calculated in kind.

The proposed model includes individuals as agents. They are able to provide for their own basic needs. If they specialize, they become more productive. They also form social ties, and barter with other agents using their own private values as the base for negotiations. The most optimal exchange options are used. Transaction costs are reduced when experience grows and private values reflect only each agents own experience from negotiations within the agents own social network. Stock accumulates through production and barter. Stock size is limited to near term usage in consumption and exchange and is taken into account when evaluating private values. Price elasticity is taken into account.

Test runs show robustly that the modeled economy grows and reaches a high level and starts to produce economic cycles. Total utility can be calculated separately from gross production. Value of the most common exchange media has larger variation than income calculated as needs satisfaction. Transaction costs grow considerably with economic growth due to high specialization leading to longer supply chains. Equilibrium characteristics of money values cannot properly be calculated as agents are on different roles in the value chain, but the average values show clear tendency to reach equilibrium. The model is clearly well behaved and can be used to study detailed effects of single variables. The software can contain programming mistakes, but testing and cross checks have not revealed any serious inconsistency in the results and there are no conceivable programming mistakes that could produce the positive results. However, these are initial results only and extensive further study is required.

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