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Abstract

Agent-based Keynesian economics is an implementation of a suggested three-step analysis that allows our analysis to be macrofounded as well as agent-based. Step one is a study of the macro-properties of economic systems. Step two is a microanalysis of economic behavior taking into account the macro-properties. The final step is an agent-based computational model. The model is employed for the study of business cycles and the relation between growth and inequality.

1 Introduction

In an era where New Keynesians coexist with Post Keynesians, calling a model Keynesian may appear to be foolhardy or even pointless. The combination of Keynesian macroeconomic theory and agent-based computational modeling does, however, appear to be a fruitful approach. Naming the approach agent-based Keynesian economics serves several purposes. From a methodological point of view, specifying a particular approach to agent-based computational economics is meant to stress the fact that agent-based simulation techniques are merely a tool for economics; not a new revelation that should make all economists work along the same path. The approach might have been called agent-based macroeconomics since it is not a strict reproduction of Keynes' work, and primarily differs from most agent-based models by allowing a role for macroeconomics as more than emerging properties. In an era where representative agent macroeconomics is in a dominating role, the concept of macroeconomics has, however, become rather weak, and the term Keynesian appear more appropriate for our purpose.

What distinguishes agent-based Keynesian economics from agent-based computational economics in general, which tends to focus on exchange processes,

*source code and an executable version of the model may be found at this homepage.

is the role played by money, comprising the role played by monetary prices as stabilizing devices rather than relative prices as market clearing devices and the role played by monetary values in economic decision making. Keynesian macrotheory was allegedly dismissed because of its lack of microfoundation, but it could not be microfounded with the tools available at the time of its dismissal. Using agent-based computational techniques, Keynesian macrotheory may be microfounded without loosing its sting. Here we shall study possible causes of sub-optimal behavior of economic systems using Keynes' theory of monetary production'. But the model presented may be, and is also in the present work, extended with other theoretical elements and the approach may also prove to be a potent tool for policy analysis.

2 Three-step analysis: Macro, Micro and Simulat ion

It is often argued that Keynes' General Theory is a macrotheory without any microfoundation, and that this lack of microfoundation was the reason why many economists turned their back on Keynes about 30 years ago. Since then lack of microfoundation has been a legitimate reason for dismissing economic theories[2]. From a logical point of view it is not easy to understand how a lacking microfoundation can be a sufficient deficiency for dismissing a theory, but even granting this dogma, it is hard to see why this should dismantle Keynesian theory completely. Whereas Keynes did base his theory on microeconomic considerations, but was unable to formalize the relation between micro and macro because his theories required the possibility for agents to be different, his modern critics do have a formal microfoundation, but they get this by modeling a multitude of similar agents, i.e. by using a representative agent. As noted by Boland (1982), Keynes was more concerned with the lacking macrofoundation of microeconomics than the microfoundation of macroeconomics.

If it is believed that money and finance matters, that the multiplicity of agents matters, that the distribution of wealth matters, i.e. that the economy might work differently if actually we were all the same, then it is not possible to make use of the representative agent[3], and without the representative agent it is impossible to provide macroeconomics with a formal microfoundation using analytical tools. Analysis simply becomes to complex to handle if one wants to allow for differences among agents. The choice has been between suppressing real world heterogeneity or giving up on a formalization of the relation between micro and macro. For Keynes the alternative was to refer to behavioral generalities and omit a formal microfoundation. But today we have a new alternative since we may overcome the analytical complexity by modeling a multitude of agents using agent-based techniques. Mirowsky and Somefun (1998) pose the very relevant question of " ***What the theoretical acknowledgement of the funda-***

'Keynes introduced the term theory of monetary production in some of his preliminary studies for the general theory and studying the general theory from the perspective of some of these preliminary studies has resulted in interpretations that differs from the standard ISLM interpretation.

[2] As noted by Solow (1986) the demand for microfoundation has in reality been a demand for Walrasian microfoundation.

[3] This point has been consummately discussed by Kirman (1992).

mental ***heterogeneity*** of agents ***is intended to achieve",*** thereby indicating that allowing for heterogeneity in itself does not bring us closer to any truth. For the present work the answer to this question is very clear; it is intended to let surpluses and deficits, i.e. money, matter. How can money matter to a representative agent, and how can effects of the dispersion of wealth be studied using a representative agent? It is not necessary for agents to be differently specified to serve this purpose, but they must be able to take different wealth positions.

Agent-based techniques work from the bottom up. They specify a number of micro-entities and let them interact without any global control, and it is from this interaction that macro-properties emerge. Economists need to start thinking in different ways in order to use the agent-based techniques. It is not an analytical or deductive method, and thus we cannot use the approach to prove theorems. The method is synthetic in the sense that it requires that we reproduce aspects of the real world in order to understand them, i.e. we must "grow it" rather than proving it[4]. We also need to give up quantitative prediction and settle for qualitative understanding. The advantage is that we can study properties as the apparent selforganising mechanism of economic systems without introducing such artifacts as an auctioneer or an invisible hand.

The introduction of agent-based techniques does not render "old-fashioned" macroeconomics useless. In studying an economic system it is important to study its macro-properties as well as its micro-properties. First of all we have to allow for the possibility that some economic phenomena are macro-phenomena that cannot be understood from the bottom up. To take the classic example; without a study of macro-properties, one is easily led to a neglect of money. Studying the decision-making of an individual agent it may not appear that important whether calculations are done using monetary or real magnitudes. Using Keynesian macrotheory we shall argue that the money part is of vital importance, and this has a great impact on the way we choose to model individual behavior.

Secondly we may obtain information about certain aspects of economic systems more easily by studying aggregate relations. The aggregate relations we have in mind are the tautologies of economics; the accounting relations. Schelling (1978) observes that systems dominated by relations that must hold in the aggregate (but do not hold for the individual unit), have strong feedback effects from macro to micro, and that such systems have a high complexity. They are systems where aggregation is not simple summation. Schelling's complexity notion is in accordance with the definition by Bonabeau and Theraulaz (1995):

> [A complex system] is a network of interacting objects, agents, elements, or processes that exhibit a dynamic, aggregate behavior. The action of an object affect subsequent actions of other objects in the network, so that the action of the whole is more than the simple sum of the actions of its parts.
>
> ***E. W.*** Bonabeau and *G. Theraulaz* ***(1995)***

[4]This ***biological*** terminology also found in Epstein and Axtell (1996) has been adopted from the ***artificial life*** literature.

The main example of a complex system in Schelling (1978) is exactly the role played by accounting in economic systems[5]. It is important to realize that the accounting system is really the medium through which economic interaction takes place, and through which the feedback from macro to micro works.

The complexity of economic systems generated by the existence of relations that must hold in the aggregate, together with the possible existence of macro-phenomena, makes us suggest a three-step procedure for studying economics. First study the macro-properties of the system without implicating behavior in more than broad terms. Secondly study a single microunit, bearing the macro-properties in mind. As a third step study the interaction between macro-properties and micro-properties by allowing a whole population of microunits to interact.

It could be argued that the first step should involve only behavior independent macroeconomics, i.e. primarily accounting identities. Certain behavioral statements may, however, just as well be introduced at the macrolevel as on the microlevel. This is the case for assumptions concerning value judgement, e.g. as we shall se in the next section, general statements of motives for economic behavior. On the other hand one must be careful in letting more specific knowledge of micro units affect macroanalysis at this point, since this may lead to fallacies of composition.

In any specification of economic behavior simplification is necessary - the question here is what should guide the simplification. We start out with the macroanalysis rather than the microanalysis in order to allow knowledge of macro-properties to guide simplification choices. If, from the macroanalysis, we know that the agent's choice between saving in the form of money and saving in financial assets is important to the functioning of the economic system, then we should take extra care about the way this decision is modeled. If, on the other hand, macroanalysis tells us that a decision is not all that important to the macro-properties of a system, we can be more careless in designing the decision rules.

In the third step it is important to study the whole population in order to enforce the feedback from the macro-properties to the micro units. It is obvious that the third step cannot be carried out using analytical methods - we need computer simulations.[6] On the other hand, economists should be careful not to start directly with the computer simulation without theoretical reflections on the aspects to be modeled. If simulation is to become ***the microscope of economics***[7], it must not be the case that in simulation "anything goes". Accepting an agent-based approach, economics is no longer disciplined by the rationality assumption. A minimum requirement as a disciplinary factor for economic simulation models, could be that they are founded in economic theory. Thus simulations should be used not as a substitute for theory, but as an extension of theory.

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[5]Without using the complexity terminology the same point was argued by Stiitzel (1958) who carries out a complete behavior independent analysis.

[6]As Lane (1993) notes, the artificial worlds are mathematically well-defined, but "since the dynamics *of AWs [artificial worlds] are specified in terms of these* micro-interactions, ***it is hard to imagine that the mathematical*** description ***of emergent properties*** will ***be*** analytically ***tractable"*** (p.92).

[7]The role of simulation as the microscope of economics was suggested by Holland and Miller (1991) ***"the computer plays a role similar to the role the microscope plays for biology: It opens up new classes of questions and phenomena for*** investigation." (p.367).

3 Macro-properties: Monetary Theory of Production

As already indicated, our choice of using Keynes' theory of monetary production has to do with the role played by money in economic systems. In this section we shall work through the arguments that led us to the conclusion that real world economic systems are better understood as monetary production systems rather than as market based real-exchange systems as the Walrasian set up. The primary source for this task is the first 6 chapters of the General Theory and the preliminary studies for these chapters found at Tilton (Keynes(1933a)).

As all economists will remember from their first course on macro, Keynesianism has to do with a rejection of Say's law and involuntary unemployment. What is often missing in the textbook version of the story is what led Keynes to reject Say's law, or rather what led Keynes to reject Say's law as a guarantor of full employment[8]. From the Tilton papers we learn that this rejection was based on the behavioral observation first noted by Marx; that entrepreneurs produce in order to gain a monetary profit.

> He [Karl Marx] pointed out that the nature of production in the actual world is not, as economists seem often to suppose, a case of C-M-C' i.e. of exchanging commodity (or effort) for money in order to obtain another commodity (or effort). That may be the standpoint of the private consumer. But it is not the attitude of business which is a case of M-C-M', i.e. of parting with money for commodity (or effort) in order to obtain more money.
>
> ***Keynes (1933a) p.81***

The observation that we live in a M-C-M' economy is what takes Keynes to a rejection of Say's law. Keynes reminds us that the invalidity of Say's law in a monetary economy is not just a consequence of the fact that in a currency system money, in its function as a store of value, may be hoarded thus preventing supply from creating its own demand[9]. Reading the Tilton papers it becomes clear that the rejection of Says law holds whether we are dealing with a currency system, where the volume of money can be regarded as fixed, or a pure credit system, where money is created and destroyed as economic activity takes place.

If money merely existed as a storable medium of exchange, it would not change the basic functioning of a barter economy - and in a barter economy, Keynes agreed, supply will call forth its own demand and eventually take the economy to the full employment equilibrium[10]. Rather than its functions as a medium of exchange and a store of value, it is the function of money as a unit of account that is decisive. Economic agents measure value in terms of money, and

[8] In a closed system supply will always be equal to demand, and one may therefore claim that supply will call forth its own demand - the question is whether this is a guarantee of full employment.

[9] From the General Theory one may be left with the impression that Says law does not hold because the desire to hoard a fixed (or at least constrained) stock of money may drive up the rate of interest which again will depress the level of production by making investment projects unprofitable.

[10] This point is particularly clear in the Tilton Papers (Keynes(1933a)).

thus they value larger monetary volumes higher than lower monetary volumes. This is not because they suffer from an irrational kind of money illusion, but because they have no other way of comparing collections of goods. Once money as a unit of account is introduced we cannot go back to real magnitudes by simple deflation, and we can no longer use theories applicable to a barter economy.

The consequences of having an M-C-M' circuit is crucial with respect to the level of production. In a capitalist system entrepreneurs hold the power to determine the level of production. According to our behavioral rule, entrepreneurs will only start up production if they expect to end up with more money after production has taken place. The reason for this is not a primitive money desire - they need money in order to start up production in the following period (or purchase goods). Workers in a monetary economy do not accept promises for a part of the product as their wages; they demand money wages.

Hiring all labor offered at a wage equal to the marginal product of labor, would be the obvious thing to do, if production was a question of producing as many goods as possible. Once it is a question of making money rather than making goods, it may be more profitable to leave workers idle[11]. For the entrepreneurs the question is one of getting back at least the money that they paid the workers as wages, and preferably a little more - a monetary profit.

If the M' is to be perceived as actual money it is clear that entrepreneurs as a group cannot obtain a monetary profit unless another group in the economy accepts the necessary debt. This follows from the fact that entrepreneurs cannot produce money. Since the system cannot generate monetary profits it follows that to the extend that wage-earners do not spend their current wages on purchasing current output, entrepreneurs are forced to accept a monetary position that is below the monetary position they had before they started up production. But this does not necessarily mean that the M-C-M' condition is not fulfilled. Entrepreneurs may assign a monetary value to their real assets, and if this subjective evaluation is allowed to enter the profit calculation, then entrepreneurs as a group may experience a positive monetary profit.

An entrepreneur is likely to evaluate his capital stock in accordance with the evaluation of similar real assets on financial markets. This makes the profit calculation, and thus the production decision, depend upon the moods of the financial markets. For the individual entrepreneur owning capital stock may appear to be just as good as holding money, but for the entrepreneurs as a group, capital stock cannot be realized in the form of money - they cannot all sell at the same time. In this sense monetary production systems rests on an illusion that make them fragile[12].

Thus entrepreneurs may accept an increase in their debt if they have experienced an increase in their real wealth to which they (and maybe also the stock market) attach a positive monetary value, but they will always fear an increase in their debt that does not have such a subjective counterpart. This fear limits their willingness to perform the ***death*** leap and hire labor in order to produce, i.e. move from money which they know the value of, into real goods the value of which is unknown. Supply will always create its own demand, but the demand may be for company stock or other instruments of debt rather than for con-

[11] In Keynes' words; ***"For in an entrepreneur economy [...] the volume of employment, the marginal disutility of which is equal to the utility of its marginal product, may be 'unprofitable'*** in ***terms of*** money". Keynes(1933 (p.79))

[12] This argument is similar to the ***financial instability hypothesis*** of Minsky (1975).

sumption goods, and wage-earners hold the power to force the sale of company stock or other liabilities issued by the entrepreneurs. Say's law therefore, is no guarantee for full employment - it does not take more than an expectation of insufficient demand for consumption goods to create unemployment.

Why is a rejection of Say's law as a guarantor of full employment important to the way we study economics; couldn't we just specify our agents without any assumptions concerning Say's law, and study it as a possible emergent property in the simulation step of our analysis? If Say's law is a guarantee of full employment, then it makes sense for economics to focus on the exchange process. Demand will adapt itself to supply, and since the last worker will always produce something, it is the relation between the marginal product of labor (which is also the wage offered) and the marginal utility of leisure that sets a limit to production. In this case the time available to workers may be perceived as a stock that is always fully utilized (divided between labor and leisure) since workers have a free choice between working at the given wage and leisuring. Thus agents hold stocks of goods and labor and demand stocks of goods and leisure, and all economic activity may be treated as exchanges of these given stocks.

If workers do not have a free choice between labor and leisure, the time of the worker can no longer be perceived as a fixed stock. In this case labor plus leisure no longer necessarily amount to 24 hours a day. Labor becomes a good that only comes into existence if it is demanded[13], and macroeconomics becomes relevant as the study of the factors determining the level of production. Following our study of the macro-properties of economic systems makes us focus on the generation of income rather than the exchange process. This makes the production decision of entrepreneurs pivotal to economic analysis, with consumption demand and the re-evaluation of real wealth on financial market as its main determinants.

4 Micro-properties: Decision Rules Rather than Optimization

We have already characterized the economic system as a very complex system and in specifying economic behavior it is important to ask ***how do agents cope with the*** complexity? We propose that they must cope with the complexity in the same way as Keynes suggested that agents cope with unmeasurabilities and uncertainty; by simplifying.

Throughout his professional career Keynes took an interest in measurement, and this also influenced the way he looked at human behavior. His interest was first and foremost in the unmeasurable; the fact that we cannot have a perfect measure of value, or of probability. These issues were, in the nature of things, very abstract, but Keynes also realized that it is not only theorists that must deal with such problems; economic agents must also find ways of getting around the measurement problems. If agents use imperfect "statistical" measures and economic theorists wants to say something about behavior, they need to take

[13]This is also a part of the argument for measuring national income by measuring the total wagebill. Labor cannot be saved from one period to the other, and it is only useful if it is demanded, thus it is a good measure of what has been contributed to the economic system within a period of time.

into account the statistical measures as well, and theoretical and behavioral measurements become inseparable. That Keynes was primarily concerned with the measures used by economic agents may be illustrated by the fact that he, after stating the insolubility of the value problem, notes that:

> Nevertheless these difficulties are rightly regarded as "conundrums". They are "purely theoretical" in the sense that they never perplex, or indeed enter in any way into, business decisions and have no relevance to the causal sequence of economic events, which are clearcut and determinate in spite of the quantitative indeterminacy of these concepts. It is natural, therefore, to conclude that they not only lack precision but are unnecessary".
>
> Keynes *(1936) p.39*

Due to measurement problems economic agents cannot tame uncertainty and they cannot calculate their optimal positions in accordance with neoclassical theory. What then, do economic agents do? They use methods of decision making that are not concerned with evaluation of consequences but stems from habits, instincts etc. Economic agents are not paralyzed, but find ways around the problems.

Under the discussion of the macro-properties of the system, we already discussed the role played by money in economic decision-making. It may be that it is real goods that make agents happy, but they have no way of knowing, e.g. which wage-contract will provide them with most real goods, and thus make them most happy, at the time of entering the wage-contract. In this case the most rational thing for them to do, is to choose the wage-contract that gives them the most money. Then why not skip the monetary wage-contract and settle for a part of the product? For an agent that has obligations in monetary terms (rents, repayment of loans etc.), this is not more rational - agents have a better idea of what a money-wage can buy them than they have of what a part of the product may buy them. Entrepreneurs have an even stronger rationale for using money in their calculation, as discussed above.

The role played by money in economic decision-making according to Keynes, is very typical of the way he looked at behavior. Agents live in an uncertain and complex world, and they need tools for coping with the uncertainty and the complexity. One such tool is money and contracts in money-terms, another tool is to base decision-making on simple rules rather than trying to optimize.

> Generally speaking, in making a decision we have before us a large number of alternatives, none of which are more "rational" than the others, in the sense that we can arrange in order of merit the sum aggregate of the benefits obtainable from the complete consequences of each. To avoid being in the position of Buridan's ass, we fall back, therefore, and necessarily do so, on motives of another kind, which are not "rational" in the sense of being concerned with the evaluation of consequences, but are decided by habit, instinct, preferences, desire, will, etc.
>
> ***Keynes (1938) p.294***

It may even be argued that money came into existence as a way of coping with complexity and uncertainty. Complexity in the sense that using a unit of account reduces the number of prices that an agent must operate with, and uncertainty in the sense that using a unit of account allows an agent to compare volumes over time and to enter contracts in time. Agents can reduce uncertainty by holding assets that are denominated in the unit of account; ***"The*** possession of ***actual*** money ***lulls our*** disquietude" as Keynes noted ((1936) p.116).

These arguments for using simple decision rules rather than optimization is the most important micro-property from the work of Keynes to be used in our model building. It is not so important how exactly we specify the investment decision of the entrepreneur or the consumption decision of the worker - what is important is that we look for answers in the real world rather than in the ideal world. When economic agents in the real world have invented money as a way of dealing with uncertainty and unmeasurability, why should we remove the money and pretend that they have no problems with uncertainty and lack of an invariable standard of value? Why not look at the way real agents make decisions and try to implement that in our models? Rather than assuming complex behavior in a simple world we model simple rule-based behavior in a complex world.

5 From Micro to Macro: An Agent-Based Simulation Model

Having discussed the micro- and the macro-properties of the system separately it is now time to try and combine the two. We shall discuss the theoretical and methodological requirements for the model before we present the model itself.

5.1 Theoretical Requirements for the Model

From the theoretical discussion of the ideas of Keynes, we conclude that a simulation model based on these ideas must fulfil the following requirements:

1. A multitude of autonomous agents must be modeled in order to incorporate a true role for credit money and financial markets. Only by having a multitude of autonomous agents is it possible to study the importance of the dispersion of monetary wealth. We know that monetary holdings must add up to zero, but the sizes of the plusses and minuses are bound to have a significant importance for the functioning of the economic system.

2. The model must be complete in the sense that all accounting rules must be respected. This is necessary in order to avoid possible fallacies of composition. Whenever an agent in the system pays out money there must be a recipient, and whenever an agent receives money there must be a spender. An implication of this is that the model needs to comprise all markets, e.g. we must have a labor market although we are not particularly interested in the functioning of the labor market. One way or the other we have to transfer money from the producer to the worker.

3. Money must be used as a unit of account and the only real magnitude observed is labor hours. Agents may be allowed to estimate real magnitudes using different techniques as e.g. indexation, as it happens in the real world, but as modelers we must not assume that we can measure real magnitudes.

This is particularly troublesome with respect to capital since we cannot model a technical production relation in monetary terms.

4. The model must be driven by the production decision of entrepreneurs. It is an essential characteristics of a monetary production system that entrepreneurs hold the right to initiate production - or not to do so. Entrepreneurs will estimate future consumption in order to obtain a monetary profit.

5. The ongoing monetary evaluation of real capital goods on financial markets must have an impact on the production decision of entrepreneurs. This evaluation of real capital must play a vital role to the monetary profits of entrepreneurs, and thus to the production decision. Keynes found fluctuations in the marginal efficiency of capital to be the most important determinant of cycles (Keynes (1936) p.313) and he also found a close relation between financial markets and marginal efficiency of capital. Only the monetary evaluation of existing goods can make the aggregate of agents feel richer or poorer. This effect must be implemented in the model.

6. Monetary prices are a stabilizer of the economic system and not a market-clearing device. As a simplification, commodity prices and wages may therefore be regarded as fixed. As a science economics appear to be preoccupied with the idea that it is price movements that guides Adam Smith's invisible hand, i.e. that prices are central to the selforganising properties of economic systems, but an economy may show strong selforganising powers without any changes in prices.

7. Using a unit of account and using monetary prices as estimators of real values is only one way of simplifying behavior. In general human conduct is not guided by a desire to optimize utility, and habit formation may be allowed to play a central role.

8. Money is credit money, which is constantly created and destroyed. One may model institutional limitations on credit creation, but this cannot turn a credit system into a currency system.

5.2 Methodological Requirements for the Model

Beyond the requirements for our model placed by theoretical considerations, there are a number of methodological requirements that simulation models ought to fulfil. Since agent-based methods are still new there is no list of agreed upon methodological requirements. Once the assumption of rational utility optimizing agents is removed, it may appear to be the case "that any thing goes" or that simulation is just "one damned thing after another"[14]. The problem of disciplining a science that makes use of synthesis as its central method, applies to all approaches that more or less directly base themselves on the artificial life paradigm. Since the rationality assumption to a large extend has been defining for economics as a science, an answer to the question is even more important within economics.

Holland and Miller (1991) argue that while there is only one way to be fully rational there are many ways to be less rational[15]. As a disciplinary factor they suggest that one must construct agents that exhibit robust behavior across

[14] The last phrase originates from H.Putnam according to Bonabeau and Theraulaz (1995).

[15] Although requiring computability has been proved to remove that one way of behaving rational (Rustem and Velupillai (1990)).

algorithmic choices. They argue that models that are not "sensitive ***to a particular incarnation*** of ***the adaptive agent"*** have a higher validity. Bonabeau and Therauluz (1995) argue that empirical data must be what anchors artificial life models; we must accept empirical constraints since ***"the best bottom-up approach need some kind*** *of* ***validation by top-down*** data"(p.308). Does this mean that agent-based computational economics should attempt to approximate the real world as accurately as possible? Besides the disciplinary question we must not forget that there is also a question of complexity. Lane (1993) complains that "artificial economies, ***unlike the Arrow-Debreu*** model, ***lack the*** virtues associ-***ated*** with ***a high level*** *of* ***abstraction - simplicity*** and ***mathematical tractability"*** (p.194). He suggests that "functional taxonomies *of* ***the*** various ***institutional*** arrangements" are developed (e.g. ways of handling bankruptcies) and that modelers use object-oriented programming where parts are easily exchanged. Janssen (1993) proposes ***"caricature models"*** as an alternative to real data validation, where selected aspects of the real world are deliberately exaggerated. In this case the formalization is only meant as an example, and the model no longer claims to be stable. One of the advantages of simulating is that one may study possible worlds to learn more about our particular world, and for this task caricature is certainly a useful method. Further more it allows us to trade-off reality with simplicity.

As stated earlier, theoretical considerations have been the main guide in developing the present model, and the relation to the real world emphasized, has been the implementation of real world institutional facts rather than through data validation. The model may be characterized as a caricature model since certain aspects have been deliberately exaggerated, e.g. the volatility of investment has been exaggerated in order to study its impact on consumption and asset prices. We have, on the other hand, hoped for a high degree of stability, both over time and over the parameter space in order to confirm the non-price-guided self-organization. Unfortunately a library of taxonomies as suggested by Lane (1993) does not yet exists, but his advice of using object-oriented programming in a way that allows exchangeability has been followed.

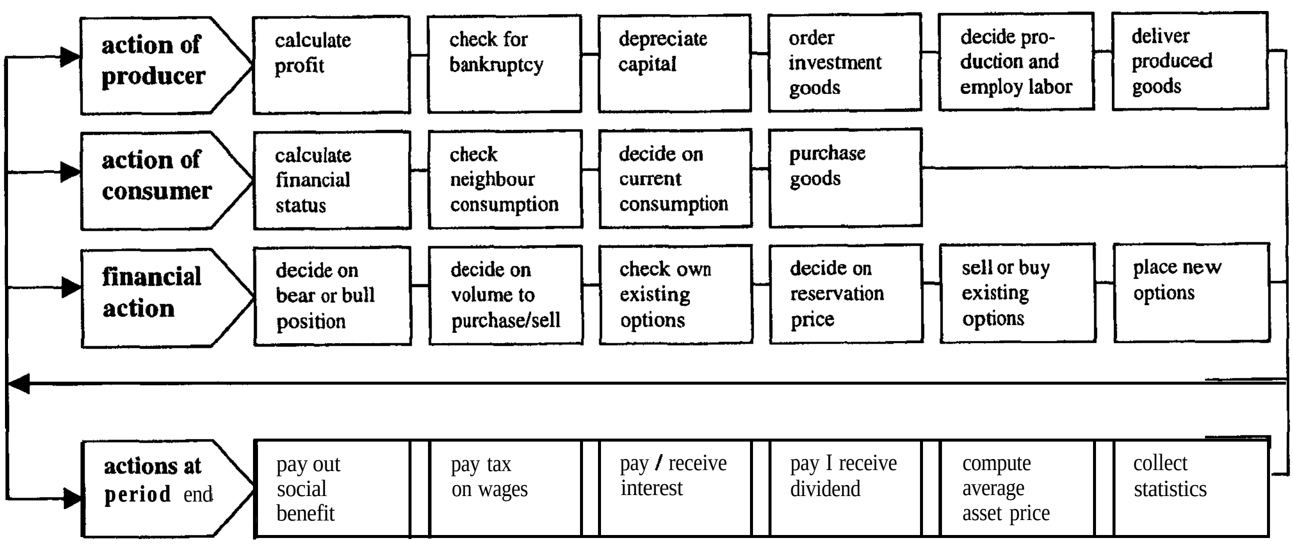
5.3 The Simulation Model

The model works by specifying a number of agents with a set of characteristics or state variables (e.g. money, capital or capacity to work), and a set of decision rules (e.g. rules for taking consumption or investment decisions). Object-oriented programming (Borland Pascal 7.0) is used so that each agent is an object with a number of state variables and a number of decision rules. The model has 3 different types of agents; consumers (who are also workers), producers of consumption goods and producers of investment goods. Inheritance is used so that all agents inherit state variables and decision rules from the "agent" object, which takes care of all financial state variables and financial decision rules. In the same way, all production units inherit from the "producer" object, which takes care of all the state variables and decision rules that the two types of producers have in common. There are also two "pseudo-agents"; a bank which takes losses from bankruptcies and charges an interest differential, and a public sector which pays out social benefit and collects taxes on wages.

The agents are autonomous in the sense that they are exposed to individual historical tracks. For example all consumers in the model start out with the same endowments and the same set of decision rules, but during the simulation they experience different historical tracks, and therefore they are no longer the same.

The model is of a cellular automaton type since consumers as well as consumption goods are distributed on a grid (a torus), in the following called consumer space. One consumer inhabits every cell, and producers, who are situated outside the grid, can place their consumption goods where they please on the grid. The grid is used for determining consumption locally as neighbor dependent.

The model runs by randomly picking an agent for action. The action to be taken may be consumption, production decision by producer of consumption goods, production decision by producer of investment goods, or financial action. Producers do not consume, but all agents take financial decisions. Production decisions are only taken once within a statistical period whereas consumption decisions are taken on average 3 times within a statistical period, and the financial decision is taken on average 2.6 times within a statistical period. Initially an ordering of all producers is generated randomly, and throughout the simulation producers take turn in performing their decision rules in accordance with this ordering. When all producers have acted once, the statistical period has ended and all relevant statistics is collected. Payment of interest, dividend and taxes as well as social benefit also follows the statistical period.



The coding of the model is done by specifying a number of agents as objects with a number of state variables and a number of decision rules[16] [17].

MARKET FOR CONSUMPTION GOODS : The market for consumption goods may be described as a cellular automaton with a shop and a consumer on each cell. The market object contains state variables related to the cells as shops or outlets. Since the action of the model is driven by agents, the market object does not have its own decision rules.

State Variables of the market for consumption goods :

supply (of goods to the cell)

sales (in current and previous period)

list of suppliers to the cell (producers of consumption goods)

MARKET FOR INVESTMENT GOODS : The market for investment goods is a linked list of investment projects. Investment projects may be available, i.e. producers of investment goods can pick the projects for production, or they may be under production. Investment projects are homogenous and producers of investment goods do not differentiate between different projects.

State Variables of the market for investment goods :

list of investment projects

FINANCIAL MARKET : The financial market is a linked list of assets and options to buy or sell assets. Assets all have a face value of 100, but they are traded at prices differing from the face value. For the debtor the advantage of issuing assets is that no interest rate is paid on assets. For the creditor the **advantage of purchasing assets is the possibility of selling** at a higher price, and the possibility of receiving a dividend. Options to buy or sell have a reservation price. When an agent wants to purchase or sell an asset he goes through the list to find an option that fulfills his own price condition. When a buyer and a seller is matched the price is settled as the average of the two reservation prices. Agents do not differentiate between assets issued by different producers.

State Variables of the financial market :

list of assets and options to buy or sell assets

average asset price in previous period

Decision Rules for the financial market :

Compute average asset price

AGENT is an object that defines the state variable and decision rules that all agents need whether they are entrepreneurs or workers. The financial decision is modelled in such a way that it will tend to stabilise rather than destabilise the system. The idea is similar to Keynes' idea of all agents having a "normal rate of interest". In our case the subjective "normal price" of assets depends upon the minimum and the maximum asset price experienced by that particular agent. If

[16]For practical reasons it has not been possible to program the model exactly as described here. Readers who wish to consult the code must be aware that some of the decision rules of the agents are found as decision rules of a "market" object or a "finance" object.

"Some of the decisions rules may work a little different for the first initial periods in order to get the system going. For the sake of the simplicity of the exposition, such initial exceptions are ignored in the following description. The reader is referred to the source code (//http:/www.socsci.auc.dk/~cbruun).

the asset price gets very high compared to the minimum asset price perceived, agents will tend to sell asset, and opposite they will tend to buy assets if asset prices get very low compared to the maximum price perceived.

State Variables of agent :

money (may be positive as well as negative) in current and in previous period

asset price (last observed asset price and average price in previous period)

minimum asset price (the lowest observed asset price, initially 75% of face value of assets)

maximum asset price (the highest observed asset price, initially 125% of face value of assets)

number of assets (held in current and in previous period)

loss (losses due to bankruptcy in current period)

dividend (dividend paid on assets held)

Decision **Rules for agent :**

Decide on bear/bull position :
if (dividend+loss) < (interest rate * value of assets held) then take bear position.

Decide on sale/purchase of assets (no: number of assets to be sold or purchased)
if (money > asset price) then (no = money/(2*asset price))
else (no = money/asset price)
if (asset price > 1.25 * minimum asset price) then (no = no - 2)
if (asset price > 1.5 * minimum asset price) then (no = no - 2)
if (asset price > 2 * minimum asset price) then (no = no - 2)
if (asset price > 2.5 * minimum asset price) then (no = no - 2)
if (asset price < 0.75 * maximum asset price) then (no = no + 2)
if (asset price < 0.5 * maximum asset price) then (no = no + 2)
if bear position and (no < 0) then (no = no * 2)
if bear position and (no > 0) then (no = no / 2)
Make sure that only entrepreneurs attempt to sell more assets than they hold.

Decide on reservation price : The price condition is set equal to the last asset price observed by the agent. If the agent wants to buy, but already has unsatisfied purchase option on the market, the price condition is increased with 10%. If the agent wants to sell and already has options for sale on the market, then the selling condition is reduced with 10%.

Check existing options on the market placed by the agent: The agent must go through the list of existing assets in order to put up assets owned by itself for sale, to remove existing options for sale or purchase no longer wanted, or to change the price condition on existing options.

Sell or buy on existing options : Check existing options in order to find trading partners. Buy assets from agents that have placed a sell-option with a lower reservation price than the condition for purchase, or sell assets to agents that have placed a buy-option with a higher reservation price than the condition for selling. The final price is determined as an average of the two reservation prices.

Place new options for sale or purchase if desired transactions could not be obtained.

Pay interest : At the end of every period agents with negative money holdings pays interest to agents with positive money holdings. If the bank has experienced large losses due to bankruptcies, it will impose an interest differential in order to cover its loss.

Check price level at asset market : At the end of every period an average price of all assets traded within the period is found and made public to all agents. This price is treated as the last observed price by all agents[18].

PRODUCER inherits all state variables and all decision rules of the **agent.** The most important decision rule is the decision to invest. Since we set out to only measure labour hours and monetary volumes, it is not possible for us to link capital to production capacity - production functions must be in real terms. Following, the production capacity of producers in our model is not limited by their willingnes to invest. However, producers still invest, and it may also be profitable to do so, since they may obtain a capital gain by investing and selling assets on the financial market.

State Variables of producer :

production (in current and previous period)

proflt

list of capital goods

number of assets issued (at beginning of current and beginning of previous period)

Decision Rules of producer :

Calculate profit : Profit is calculated as the difference between the wealth position of the producer at the beginning of previous period and the wealth position at the beginning of current period. The following principles for evaluation are used:

Capital goods are evaluated at their cost price at time of purchase.

Assets held are evaluated at average asset price in previous period.

Assets issued are evaluated at their face value, not their market price.

Stocks **of unsold goods** are not assigned any value.

Check for bankruptcy : The wealth position of the producer is calculated using the same principles as in the calculation of profit.
If (financial status < (bankruptcy * current production))
and (financial status < bankruptcy * initial production)
then bankruptcy is declared.
Bankruptcy is a parameter that may be varied for experimentation. In the present simulation it is set to 10.

Perform bankruptcy : Holders of assets issued by the producer that is declared bankrupt loose them. If the producer has a negative money account the bank takes the loss. If the producer has a positive money account the money is distributed among the holders of assets issued by the producer as a compensation for their asset loss. The producer is initialised as a new producer.

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[18] For alternative experiments one may choose not to make this price public and thus only use the local price.

Order investment goods :

if (profit > 0) and (asset price > nominal asset value) and (money > 0) then (invest=2)
if (profit > 0) and (asset price > nominal asset value) and (money < 0) then (invest=l)
if (asset price > 1.25 * nominal asset value) then (invest = invest * 2)
if (money > 2*iniinvest) then (invest = invest * 2)
(invest=invest+1)
iniinvest is a fixed parameter also used for determining investment in the initial periods.
Investment orderings are placed on a list from which producers of investment goods pick them.

Depreciate capital : All capital goods that are more than 10 periods **old are** removed.

Employ labour : (employment = mark-up * current production)
mark-up is a parameter denoting the relation between production costs and the price of the product. In the present experiments it is set to 0.8. If (mark-up = 1) then production cost is equal to the price of the final product, i.e. there is no profit share. Production costs may be regarded as only labour costs or as labour costs plus capital costs. In the default run half of the capital cost, measured as the purchasing price of capital held divided by the lifetime of the capital, is regarded as a production cost.The workers have a maximum worktime and the entrepreneurs have a maximum employment time per worker. If an entrepreneur has 100 attempts of finding unemployed labour without success, he reduces his production plans in stead. Such an incident is recorded as a case of full employment.

Pay dividend : Entrepreneurs pay dividends to the holders of the assets that they have issued. The dividend may be related to the monetary profit of the entrepreneur or it may be related to current interest rate. In the default setting a mix of the two dividend principles is chosen;
if (profit > (4 * interest rate * assets issued)) then pay out dividends that axe twice as high as interest payments, else do not pay out dividends.

PRODUCER OF CONSUMPTION GOODS : Inherits all state variables and decision rules from the producer object and thus from the agent object.

State Variables of producer of consumption goods :

list of sales on the different cells in the consumption space.

last periods sales

Decision rules :

Decide on current production :
if (profit>O) then (current production = 1.1 * last periods sales)
else (current production = 0.9 * last periods sales).

Employ labour : Producers of consumption goods prefer to hire labour in the areas of the consumption space where they sell the most. This assumption is made in order to allow rich and poor neighborhoods to evolve and thus allow the study of dispersion. The entrepreneur first gives employment to the worker that inhabits the cell where he has sold the most and the four neighbours of this cell. Then he moves on to employ the workers on and around the cell where he has had the second highest sale. If his need for labour is not satisfied with this rule then he randomly draws workers.

Make sales list : Sort the cells on which goods where sold during the last period according to sales volume.

Place goods : Starting from the cell that had the highest sale, place 5% more on each cell than was sold on the cell during the last period. If, however, the cell already holds more than (5*last periods sales), then skip the cell and move on to the next cell on the list. If not all goods are placed with this rule, then place the rest randomly.

PRODUCER OF INVESTMENT GOODS : Inherits all state variables and decision rules from the producer object and thus from the agent object. Investment goods are only produced on demand, and all investment projects have the same size.

State variables of producer of investment goods :

Number of production projects (in current and previous period)

Decision rules for producer of investment goods :

Decide on current number of investment projects to produce . Take in 50% more projects than last period, or at least 5 production projects, unless profit was negative in which case only half the number of last periods projects is taken in ex ante. Pick the current number (or as many as possible) of projects from the list of available investment projects. There is no guarantee that the desired number of investment projects are available.

Employ labour : Producers of investment goods pick all labour randomly from the consumption space. See details in decision rules of producer of consumption goods.

CONSUMER : The consumers are distributed over the consumption space so that one consumer inhabits each cell. Consumers inherit all state variables and decision rules from the agent object. The consumption decision is inspired by J.S.Duensenberry's consumption theory[19] in that the consumption of an agent is determined by the consumption of its neighbours.

State variables of consumer :

list of neighbours in the consumption space

consumption (in current and previous period)

wage-income (in current and previous period)

Decision rules for consumer :

Find neighbours : The address of the 5 Von Neuman neighbours is found. Since consumers do not move, neighbours only need to be found initially. The edges of the consumer space are connected so that all agents have the same number of neighbours.

Check neighbour consumption : Calculate the average consumption of neighbours (own consumption included).

Calculate financial status :

wealth position = money + assets evaluated at last observed market price
windfall profit = increase in value of assets held + dividend received + loss due to bankruptcy - opportunity cost in holding assets (interest rate not received).

[19] Duesenberry (1949) emphasised interrelatedness and non-reversibility of consumption.

Decide on desired consumption in current period :
consumption = average neighbour consumption
if (wealth position < credit squeeze) or (windfall profit < credit squeeze) then (consumption = 0.75 * consumption)
if (wealth position > wealth squeeze) or (windfall profit > credit squeeze) then (consumption = 1.25 * consumption)
if (consumption < existential minimum) then (consumption = existential minimum)
Where credit squeeze and wealth squeeze are parameters set to 3 by default, but varied between 1 and 7 for the study of distribution. Existential minimum is set to 50.

Find difference between actual and desired consumption : If actual consumption, i.e. the consumption that has already taken place within the current period, is equal to or larger than desired consumption then stop the act, else purchase the desired volume.

Purchase goods : First buy the goods on the cell inhabited on a first placed, first purchased basis. If the inhabited cell did not hold sufficient goods, then go to the neighbouring cells one by one and purchase goods until desired consumption is reached or until all neighbouring cells have been visited. When a good is purchased, money is transferred to the producer of the consumption good, and the sale is registered in the sales list of the producer and on the saleslist of the cell in the consumption space.

Receive social benefit :
if ((money < negative finance impact) and (assets = 0)) or (wage = 0) then (money = money+existential minimum) and (banks money = banks money-existential minimum)
Where existential minimum is a fixed parameter set to 50.

Pay tax on wage : All money paid out as social benefit is collected by a proportional tax on wages.

6 Simulation Results

Many different experiments have been performed with the model, but here we shall restrict ourselves to the presentation of two basic results, one on the relation between distribution and growth, the other concerning business cycles.

6.1 The Business Cycle

For some parameter values the model generates cyclical patterns. As illustrated by figure 1 the cycles appear to be set off by an increase in asset prices which results in increasing investments. With a timelag the boom in asset prices and investment causes a rise in consumption. Asset prices do, however, not increase for ever. The supply of assets (including emission of new assets) increases due to entrepreneurs need to finance their investment expenditures, and at the same time consumers start spending more money on consumption goods. This causes a fall in asset prices and, again with a timelag, investment and consumption decrease.

Many aspects of the cyclical pattern should be expected from the way decision rules are specified. The rise in asset prices is, however, not all that obvious. The decision rule states that agents with positive money holdings will move into

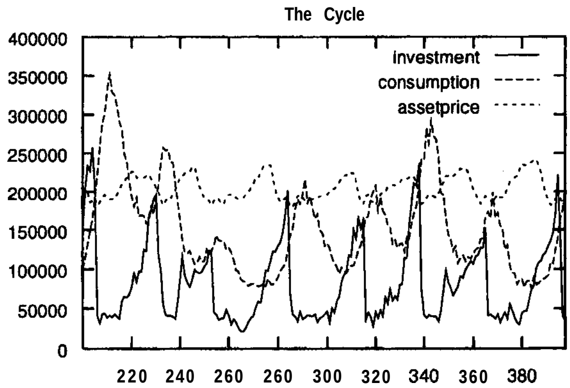

Figure 1: The cycle in the default run described above with 40*40 dimension of the consumer space. Asset prices have been multiplied by 2000 to match the remaining data.

holding assets unless the asset price is high compared to the lowest asset price observed by the agent. Agents with negative money holdings will sell assets or possibly emit new assets if they are producers, unless the asset price is very low compared to the highest asset price observed by that agent. For very high asset prices, agents with positive money holdings may choose to sell assets and for very low asset prices agents with negative money holdings may choose to buy assets. An additional rule states that agents who have experienced low pay off from their asset holdings (due to lack of dividend or losses from bankruptcies) will be more careful in their purchase of assets or more ready to sell assets. These rules should not result in a very volatile asset market, but an asset market that smoothly accommodates economic activity[20]. Further more the behaviour of surplus units is approximately symmetric to the behaviour of deficit units, and thus there is no built-in tendency for increasing or decreasing asset prices. There is, however, a built-in stabiliser since high prices will stimulate supply and depress demand.

That the offsetting increase in asset prices does not follow immediately from the described decision rules is illustrated by the fact that similar booms in asset prices do not take place if investment is fixed[21] (figure 2). If consumption is fixed (figure 3) there may be quite strong changes in asset prices, but they are rarely as strong as in figure 1, and they are certainly not as regular. We may therefore conclude that the cyclical movement in asset prices is an emergent property arising from the interaction between asset decisions, investment decision and consumption decisions.

The rise in investment as a result of the high asset prices is more apparent from the decision rules. Beyond the one unit that producers must invest to "stay in the game", investment only takes place if the the market price of assets is higher than, or equal to, the face value of assets. The rationale for this decision rule is that the emission of an asset may be perceived as selling the right to one unit of investment goods. Only if one unit of investment goods can be sold at a

[20]For later experiments it will be interesting to see how the model will react to a more volatile financial market.

[21]Fixed does not mean absolutely fixed since there is still random variation.

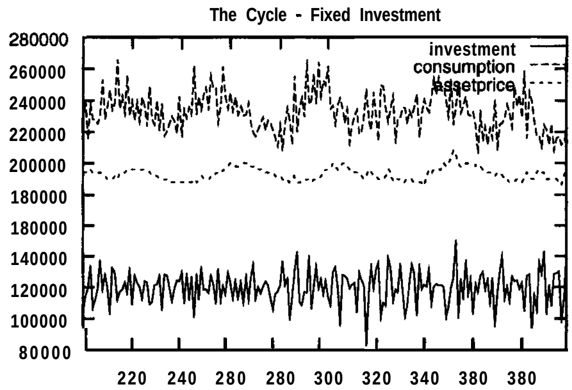

Figure 2: In this simulation all producers order 3 units of investment goods every period. Investment and consumption is volumes produced rather than volumes demanded. Asset prices have been multiplied by 2000 to match the remaining data

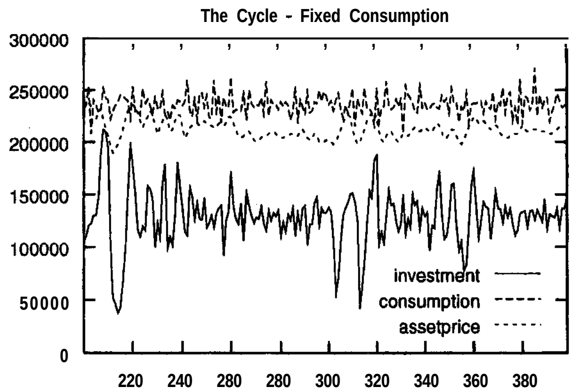

Figure 3: Consumption demand is fixed as 4*existential minimum. Asset prices have been multiplied by 2000 to match the remaining data.

price higher than its purchasing price (which is defined to be equal to the face value of an asset) is it attractive for producers to purchase investment goods[22]. That there is a strong link between movement in asset prices and investment is also demonstrated by the fact that forcing asset prices to be equal to 100 removes the strong cyclical movement in investment (figure 4).

There are two factors causing the rise in consumption; the rise in asset prices will in itself cause a rise in investment because it will increase the wealth position of agents, but a large windfall profit may also be the direct cause for an increase in consumption. The income generated by the rise in investment will also make agents feel wealthier and thus tend to increase consumption. Taking into consideration the timelag, the effect from investment appears to be the most important. Both effects are, however, indirect since consumption is primarily determined by the consumption of neighbours. Only the agents that experience the largest windfall profits or hold the largest wealth will increase

[22] The reader may look for a relation between investment and production. The search is in vain. As described under the third theoretical requirement for the model, our nominalist approach does not allow us to model a technical production function.

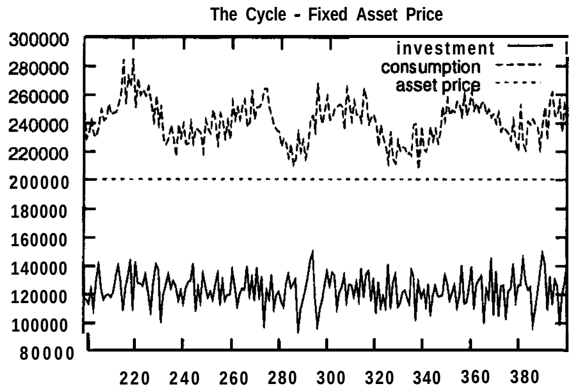

Figure 4: Asset prices are fixed at their face value (100). Asset prices have been multiplied by 2000 to match the remaining data.

consumption relative to neighbours.

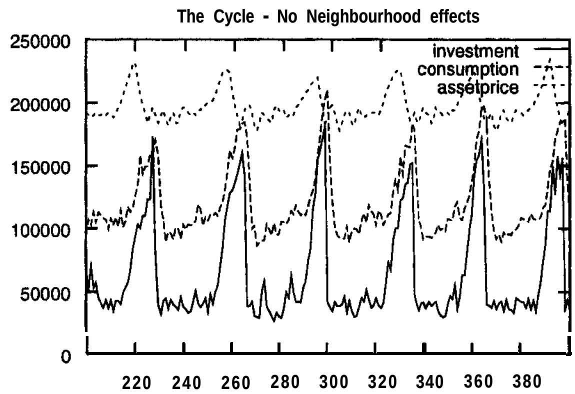

Figure 5: Consumption demand is set to (0.8*wage) in previous period and all labour is hired randomly from the space of consumers. Asset prices have been multiplied by 2000 to match the remaining data.

The neighbourhood dependency implies that consumption may live a dynamics of its own[23]. This is illustrated by figure 4, where consumption appear to be cyclical although the asset price is fixed and there are no cycles in investment. How much the neighbourhood means to the result may be seen from figure 5 where neighbourhood effects is removed in consumption as well as employment. The consumption function is replaced by a simple Keynesian consumption function letting agents consume 80% of last periods wage. In this case the relatively long lag from investment to consumption has disappeared and the cycles are much more regular.

What exactly is it that makes the cycle turn? One hypothesis may be that the system runs into a full employment constraint. Full employment cannot be measured on our nominal scale since there is a markup on capital costs as well as labor costs. In principle production may boom forever by employing more

[23] A similar result was found in Bruun (1996) where the production side is ignored.

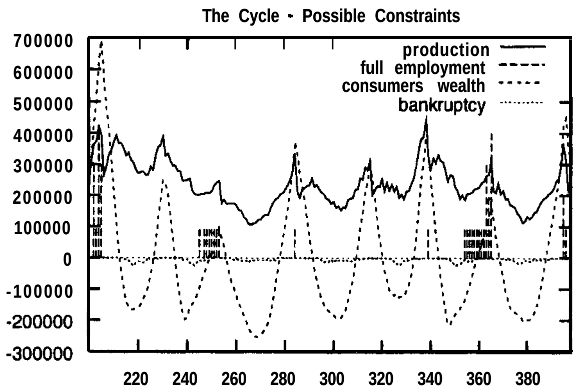

Figure 6: Full employment is the number of producers that have had to cut back on planned production due to lack of labour. The number has been multiplied by 100.000 to match the remaining data.

and more capital in production. In figure 6 full employment is measured as the number of producers that run into a full employment constraint, i.e. producers that must cut back on production because they cannot find the needed labor. Around period 360 the boom may have been stopped by lack of labor, but it is not the general picture, and for some of the other experiments, employment constraints are rare events. Bankruptcies follow the cyclical pattern but they merely seem to follow investment expenses and can hardly explain any of the turning points. We thus have to stick with our first hypothesis; that it is supply and demand of assets that drives the cycle. This hypothesis is also confirmed by the relation between consumers wealth and asset prices. The boom in asset prices stops, as consumers' wealth becomes positive. With an asset price around 100 this is also the time where producers wealth will become negative which will increase the supply of assets. The wealth of consumers is distributed among more agents, and many consumers may have positive money holdings which are, however, not large enough to purchase assets.

6.2 Distribution and Growth

An important result of our simulation model is that growth in income is accompanied by a more skewed distribution of income and wealth. This is a result that was also obtained by Epstein and Axtell (1996) under a variety of different assumptions. In figure 7 we clearly see the relation between growth in consumption and increasing standard deviation in consumption. The "snapshots" of the consumer space every 10 period illustrate a tendency for rich and poor neighborhoods to develop with booms. The more black and white the snapshots are the larger differences between agents. But what is cause and what is effect? Does consumption increase as a result of the larger differences, or is the larger difference a side effect of growth - a side effect that may put the growth to an end? For their model, Epstein and Axtell concludes that "there is a ***trade-off between economic equality and*** economic **performance"**, but with the cycles generated in our model one cannot talk about a trade-off, since allowing increased inequality will not make the system perform better.

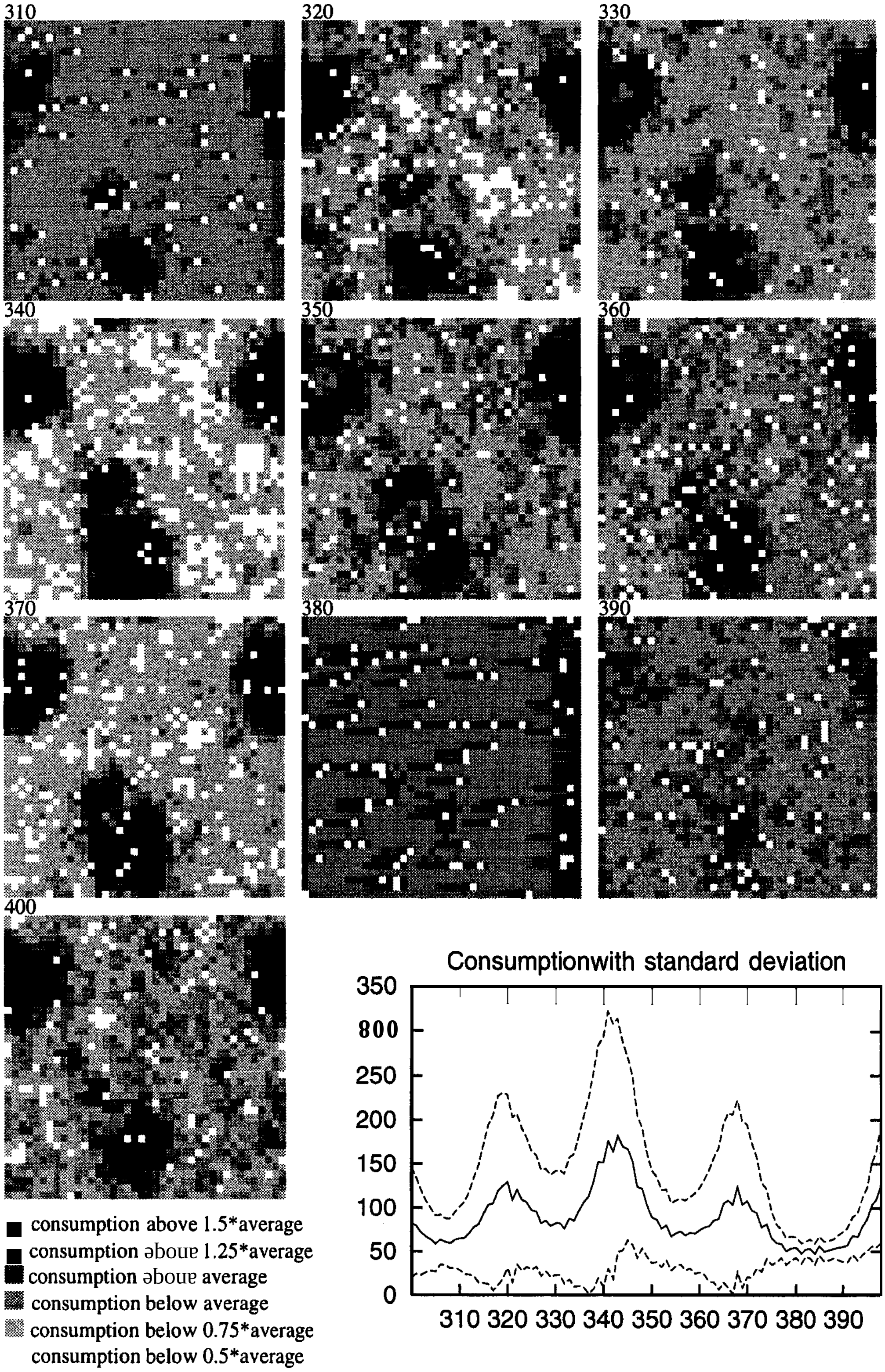

Figure 8: Snapshots of the consumer space. Dark colours indicate high consumption areas.

An important observation to make from figure 7 is that the most skewed distributions are found at the peak of the boom (e.g. in period 350 and period 370), while the largest equality is found during the through (e.g. period 330 and 380-390). The standard deviation follows the development in the snapshots. Thus inequality grows during the upswing but decreases during the down trip. The equality is what gives way for the upturn since no agents are constrained by their wealth position, but at the top some agents are no longer capable of ***keeping up with the Jones's,*** and this is what stops the boom in consumption.

We have defined two variables in our system that allows us to manipulate with the tendencies for inequality in wealth. A "credit squeeze", which determines how large deficits consumers build up before it affects their consumption negatively, and a "wealth squeeze" determining how large surpluses consumers build up before it affects consumption positively. If Epstein and Axtell (1996) are right, we should expect the highest levels of income for the highest levels of both "squeezes" since this will generate the largest inequality. It may, however, be argued that the highest levels of income should be expected for the lowest values of the two squeezes. In this case the argument would be that for the system to experience growth, all consumers must move in step - i.e. the same argument that is usually applied to the credit creating capabilities of the banking system. There is a limit to how much credit one bank can issue, but for the banking system as a whole there is no such limit.

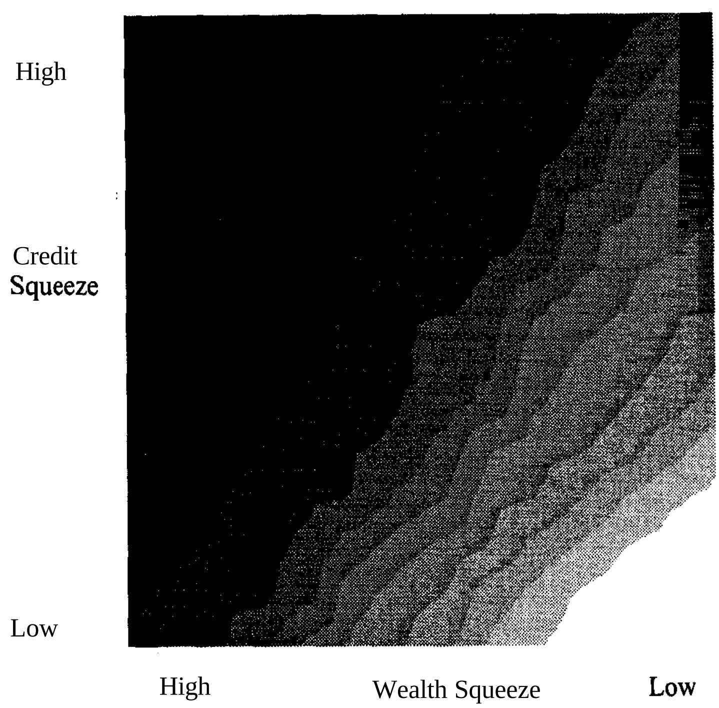

Figure 9: wealth and credit squeeze. Income varies with the credit squeeze and the wealth squeeze (described in the decision rule of the consumer) from a range below 33.100 for the darkest colour to above 184.900 for the brightest colour. The numbers are calculated as the average of ten simulations with different seeds to the random generator. The length of each simulation was 250 periods and the dimension of the consumer space was 20*20.

From figure 9 we may observe that the highest levels of income are found with a low credit squeeze and a high wealth squeeze. Despite the discrepancy from the hypothesis stated above, this is not very surprising; when the poor are allowed to maintain their deficits and the rich are forced to spend their surpluses, we should find a high income. This result is very relevant to limits to growth in the real world since in the real world institutional set-up, constraints are normally found to be the exact opposite; a stronger pressure on deficit units than on surplus units. Creating inequality will just impose the limit to growth earlier than the case where the model creates its own inequality. It is therefore, in our setup at least, wrong to suggest that we have a choice between growth and equality; growth comes together with inequality, but the inequality is what sets a limit to growth.

7 Conclusion

Our method of analysis has been, first to analyze the macro-properties of the system we want to study, then its micro-properties and finally to relate the two by using an agent-based model. Although the agent-based approach is a bottom-up approach where macro is generated from micro, starting out with the macro-properties did affect the way we modeled micro entities. First of all it meant that we did not model the economy as exchange of preexisting stocks of goods, and we did not model relative prices as the central coordinator between supply and demand for stocks of goods. By not doing this we have demonstrated that price changes are not necessary in order for the selforganising properties of an economy to work.

Although our artificial economy does not operate at maximum capacity level, it does operate quite stable over a wide parameter space. In some areas of the parameter space, the asset prices have a tendency to boom, in other areas we get nice cycles, or a system that never get above the level of existential minimum. But this is also the case with models that use prices as the selforganising mechanism. Thus the results of our simulation open up for a relevance of Keynesian macroeconomic theory, and hopefully it will enable us to extend this theory.

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