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Bruun, Charlotte

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Charlotte Bruun
Department of Economics, Politics and Public Administration
Aalborg University
9000 Aalborg
Denmark
cbruun@epa.aau.dk

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Abstract

The aim of this paper is to use agent-based computational economics to explore the economic thinking of Keynes. Taking his starting point at the macroeconomic level, Keynes argued that economic systems are characterized by fundamental uncertainty - an uncertainty that makes rule-based behaviour and reliance on monetary magnitudes more optimal to the economic agent than profit- and utility optimization in the traditional sense. Unfortunately more systematic studies of the properties of such a system was not possible at the time of Keynes. The system envisioned by Keynes holds a lot of properties in commen with what we today call complex dynamic systems, and today we may apply the method of agent-based computational economics to the ideas of Keynes. The presented agent-based Keynesian model demonstrate, as argued by Keynes, that the economy can selforganize without relying on price movement as an equilibrating factor.In our implementation selforganization does, however, not mean a steady long run equilibrium, but a tendency to generate cycles.

1 Introduction

Seven decades after the publication of The General Theory, the ideas of Keynes are still alive, although in several different guises. We have New Keynesians coexisting with Post Keynesians while the ISLM model of Bastard Keynesians has proven to be difficult to drive out of economic thinking. Here yet another Keynes interpretation will be presented with the merit of using agent-based computational methods in an attempt of uniting the macroeconomic ideas of Keynes with his behavioral ideas. The seven decades of Keynes interpretations

will be largely ignored in favor of a rereading of Keynes from an agent-based computational perspective[1].

It is often claimed that Keynesian economics has no microfoundation. Although Keynes was primarily concerned with the macrofoundation of economic systems, he certainly did have ideas about microbehaviour - although different from the dominant microeconomic reasoning of both his and our time. The approach to be developed here will attempt to identify and develop the micro reasoning of Keynes and embed them in his macroframework. Following we shall employ a 3-step analysis; first we shall present the macrofoundation of Keynes, next we shall discuss his microfoundation and finally we shall attempt to unify the two in an agent-based computational model.

Gaffeo et al (2007) make a strong point of microfounding macroeconomics using agent-based methods rather than optimization. Still they retain the mainstream general equilibrium theory as their reference model, with decentralized trade and adaptive behavior as the only deviations. However mainstream economics did become mainstream exactly because it is analytically solvable when optimizing behavior is assumed. Using a framework of agent-based computational economics, the argument for using general equilibrium theory as a reference model disappear, since it is no longer more solvable or less ad hoc than other approaches. This provides us with a unique opportunity of reconsidering other approaches - among these the original approach of Keynes.

2 The Macrofoundation of Keynes

In his Tilton papers (Keynes 1933a) and the first 6 chapters of The General Theory, Keynes introduced the idea of a monetary production theory. Taking this starting point, the liquidity preference theory of the rate of interest is not vital to Keynesian economics. What is central is the fact that we live in a monetary economy and that, given fundamental uncertainty, we have no way of reconciling monetary and real magnitudes.

Keynes' option for monetary magnitudes is motivated both from a valuetheoretic perspective and from a behavioral perspective. In his *choice of units*, Keynes addresses the value problem: How do we measure *the community's output of goods and services [which] is a non-homogeneous complex*? Real magnitudes may be chosen for partial analysis, but for macroeconomic analysis Keynes well known solution was to apply two fundamental units: money volumes and labor hours. This brings him to national income accounting and the macroeconomic logic of the system. Entrepreneurs hold the power to determine effective demand since the wages they pay out in their production process are also the sum available for purchasing the final product.

Keynes' behavioral motivation for choosing monetary magnitudes concentrates on the profit calculation performed by entrepreneurs.

[1] It should be noted that Leijonhufvud (2006) and Foster (2004) both have a similar rereadings of Keynes in light of the complexity approach, but without the computational implementation.

> The firm is dealing throughout in terms of sums of money. It has no object in the world except to end up with more money than it started with. That is the essential characteristic of an entrepreneur economy.
>
> *Keynes(1933) p. 89*

Especially the entrepreneurs face the fundamental uncertainty. As in neoclassical economics, entrepreneurs strive to maximize profits - the focal point to Keynes is that it is monetary profits rather than real profits they strive for.

> 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 (1933) p.81*

The consequences of having an M-C-M' circuit is crucial with respect to the level of production. 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[2]. For the entrepreneurs the question is one of getting back at least the money that they paid the workers as wages, and preferably more - a monetary profit. This question must be addressed at the macrolevel. In the aggregate there is only one way of getting back this money for the entrepreneurs as a class without entering new debt; by selling consumption goods. If workers prefer to save some of their wages, whether they hoard the money, open a savings account or purchase a financial asset, entrepreneurs will end up with a larger debt, and apparently a negative monetary profit[3].

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 extent 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

[2]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))

[3]This conclusion is drawn under the assumption that no other sector in the economy; public sector or foreign countries, changes its debt position.

not fulfilled. Keynes is not very clear on this, but for the system to work, entrepreneurs must assign a monetary value to their real assets. If this subjective evaluation is allowed to enter the profit calculation, then entrepreneurs as a group may experience a positive monetary profit.

This makes the profit calculation and thus the production decision depend upon the moods of the financial markets. Financial markets are not only mediators between investors and savers, they also evaluate future returns on stock, and thus its monetary value. For the individual entrepreneur owning capital stock to which a monetary value is attached may appear to be just as good as holding money, but for the entrepreneurs as a whole, 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.

3 The Microbehaviour: Rules of Thumb Rather Than Optimization

Throughout his professional carreer 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. Keynes 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 want to say something about behavior, they need to take into account the statistical measures as well and the theoretical and behavioral measurements become inseparable. One could call this reversed rational expectations! 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 clear-cut 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. 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.

> 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*

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. Combining rules of thumb with a macrofoundation adds up to the complexity dictum of our time; the rationality may lie with the system and not with the individual. 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? Rather than assuming complex behavior in a simple world we model simple rule-based behavior in a complex world.

4 Modeling Guidelines

Having discussed the macro- and the microproporties of the system separately, it is now time to combine the two. Before presenting the actual model, let us discuss some of the methodological guidelines for a Keynesian model, and some of the simplifications made.

It cannot be emphasized strongly enough that what we are interested in, is the macroproporties of the system. Our aim is not to describe actual behavior of economic agents, but to investigate macroproporties given a simple behavior of economic agents. The main question thus becomes; does the system in itself hold enough *rationality* for it to function reasonably, without relying on a high degree of rationality of the economic agents.

Given this motivation we aim to depend as little as possible on random processes. We want to assume simple rule-based, but purposive, behavior. Random processes only enter the decision making of economic agents with respect to placing consumption goods and hiring labor, and for picking which agents gets to act.

Neither have we introduced any growth components in the model. We do not set out to explain economic growth, but to study the qualities of a given system with a given production technology.

The guidelines of simple behavior are as far as possible given by Keynes. Agents rely on monetary volumes and the selforganizing features are based on quantity adjustments rather than price adjustments. Only in the stock market do price adjustment take place.

With respect to consumer behavior we have expanded on the ideas of Keynes. *All production is for the purpose of ultimately satisfying a consumer* Keynes states, but in spite of this he leaves us in a limbo concerning, what actually determines consumption since in *The General Theory* he takes the subjective factors, i.e. the psychological characteristics, as given. We are left with the interdependence of income and consumption - but what drives the system? In the model we have tried to elaborate on the psychological factors by reference to Duesenberry(1949) who introduced the idea of neighbor dependence in consumption.

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 to the functioning of the economic system.

Agents being, in this sense, autonomous, we need not introduce heterogeneity - it will emerge when running the model. Thus we let all agents within their respective class (producer of consumption good, producer of investment good or consumer) start up as exactly equal.

An important aspect of the model is what may be called feedback from macro to micro. In order for this to happen the model must be complete in the sense that all accounting rules must be respected. Whenever an agent in the system pays out money there must be a recipient, and whenever an agent receives money, another agent must have paid out that money. An implication of this is that the model needs to model 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.

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. Here we have chosen to bend our principle in order to have capital goods in the production function. We do not introduce a traditional production function with substitution between labor and capital, but merely set a limit to how much an entrepreneur can produce with a given volume of capital.

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. This is an aspect that has later been emphasized by Minsky. 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.

5 The Agent-Based Keynesian Model

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

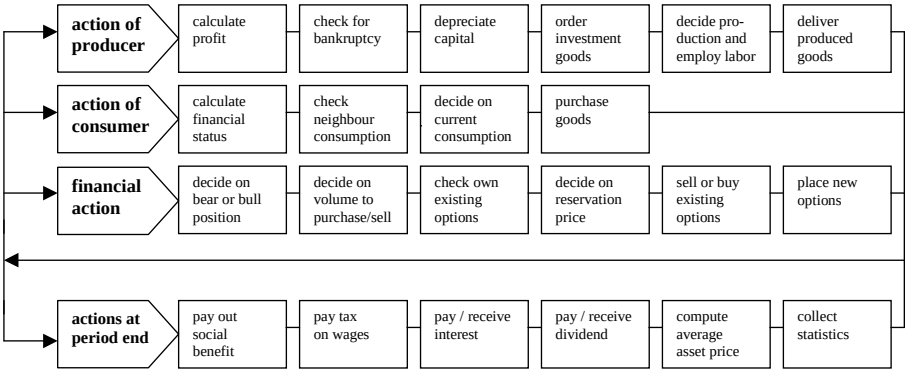

Figure 1: Decision procedures.

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. 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. 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.

5.1 Production of Consumption Goods

There are two main determinants of the production decision; last periods sales and last periods monetary profits. Monetary profits are calculated according to the following rule:

$$\pi_{it} = (M_{it} - M_{it-1}) + (p_t S_{it} - p_{t-1} S_{it-1}) + (\rho K_{it} - \rho K_{it-1}) - (\rho S^I_{it} - \rho S^I_{it-1}) \quad (1)$$

Where M_{it} is money holdings (positive or negative banking account) of producer i in period t, S_{it} is stock held, K_{it} is production capital and S^I_{it} is stock issued. p_t is the average price of traded stock in period t-1. ρ is a fixed price measuring both the production price of a unit of capital and the face value of stock. Monetary profit affect the production decision in the following way[4]:

$$Y^{initial}_{it} = \begin{cases} Y^{sold}_{it-1} * 1.1 & \text{if } \pi_{it} > 0 \\ Y^{sold}_{it-1} * 0.9 & \text{otherwise} \end{cases} \quad (2)$$

The producers holding of production capital may limit this initial production decision:

$$Y^{max}_{it} = \alpha_{it} K_{it} \quad (3)$$

where α_{it} is capital productivity. There is no substitution between capital and labor so Y^{max} is the maximum a producer can produce given his capital K_{it} - no matter how much labor he employs.

$$Y^{intermediary}_{it} = \begin{cases} Y^{max}_{it} & \text{if } Y^{initial}_{it} > Y^{max}_{it} \\ Y^{initial}_{it} & \text{otherwise} \end{cases} \quad (4)$$

Since Y_{it} is monetary volume of output, labor requirement is calculated as a residual based on a markup factor, μ. The markup factor determines how much of Y_{it} is dedicated to labor and capital costs. Since producers markup both their capital costs and their labor costs, required labor can be found as:

$$L^{initial}_{it} = \mu_{it}(Y^{intermediary}_{it} - \frac{\rho K_{it}}{\tau}) \quad (5)$$

where μ is the markup factor and τ is the lifetime of one unit of capital, so that $\frac{K_{it}}{\tau}$ is the cost of capital. The producer puts a markup on all his capital, whether it is currently employed or not.

The producer may also be limited by available labor, L^{final}:

$$Y^{final}_{it} = \begin{cases} \frac{L^{final}}{\mu} + \frac{\rho K}{\tau} & \text{if } L^{initial}_{it} > L^{final}_{it} \\ Y^{intermediary}_{it} & \text{otherwise} \end{cases} \quad (6)$$

Once produced, Y is distributed to the consumer space in accordance with previous sales and a random factor. There is no price mechanism equilibrating the market for consumption goods. Goods that are not sold within the period do not perish but remains at the market as unsold stock[5].

[4] Rather than describing the final decision in one relation, a notation of initial, intermediary and final decision is chosen.

[5] Notice that unsold stock does not enter the profit calculation - with respect to monetary profit it is regarded as a loss.

5.2 Production of Investment Goods

The guiding principles of production of consumption goods also applies to production of investment goods. There are, however, some differences due to the fact that investment goods are only produced to order, and a unit of investment goods is much larger that a unit of consumption goods, which is set to one. Since the number of investment projects a producer of investment goods take in is smaller, the number of projects is allowed to vary more:

$$Y_{it}^{initial} = \begin{cases} projects_{it-1} * 1.5 * \rho & \text{if } \pi_{it} > 0 \\ projects_{it-1} * 0.5 * \rho & \text{otherwise} \end{cases} \tag{7}$$

Where ρ is the price of one unit of production capital. The constraint of labor and capital described above for the producer of consumption goods, also applies to the producer of investment goods. Thus equation 4-6 also applies to producers of investment goods.

The market of investment goods is a first in - first out list where investing firms place their orders and from where producers of investment goods pick the desired number of projects. Production of investment goods take time. If an investment project is picked from the list, it will not be delivered untill the following period. Following from this, producers of investment goods may also be limited by the number of orders at the list.

5.3 Investment

There are 4 major determinants to the investment decision; experienced capital constraint in last period, monetary profit, stock prices and money holdings.

$$K_{it}^{*} = \frac{Y_{it-1}^{initial}}{\alpha_{it-1}} \tag{8}$$

where K_{it}^{*} is the desired volume of production capital given last periods experience of capital constraint.

$$I_{it}^{initial} = K_{it}^{*} - K_{it} \tag{9}$$

High stock prices, or large money holdings may induce the producer to expand further or, in the opposite case, reduce the initial investment decision:

$$I_{it}^{intermediary} = \begin{cases} I_{it}^{initial} + 2 & \text{if } p_{it} > \rho \text{ and } M_{it} > I^{0} \\ I_{it}^{initial} + 4 & \text{if } p_{it} > 1.25\rho \text{ and } M_{it} > I^{0} \\ I_{it}^{initial} + 4 & \text{if } M_{it} > 2 * I^{0} \text{and } p_{it} > \rho \\ I_{it}^{initial} - 2 & \text{otherwise} \end{cases} \tag{10}$$

where I^{0} is a constant denoting the size of investment in the initial 3 runs of the simulation.

Finally the producer deducts from his desired investments, any investment orderings placed at the market but not yet effectuated:

$$I_{it}^{final} = I_{it}^{intermediary} - I_{it}^{placed\ orders} \tag{11}$$

5.4 Consumption

Consumption is neighbordependent with neighbors defined as Moore neighborhood in the two-dimensional consumer space. This implies that whenever a consumer gets to act, he will address his neighbors and calculate their average consumption, and this will be the initial consumption set by agent i.

$$C_{it}^{initial} = C_{neighbors}^{average} \tag{12}$$

The consumption decision is, however, also under the influence of the financial position of the consumer (W_i) as well as windfall losses or gains (V_i).

$$W_{it} = M_{it} + p_t S_{it} \tag{13}$$

where stock is evaluated at current stock prices.

$$V_{it} = (p_t - p_{t-1})S_{it-1} + D_{it} - B_{it} - i(p_{t-1}S_{it-1}) \tag{14}$$

Windfall is any gain (rise in stock price or dividend payment, D) minus loss due to bankruptcy, B, and opportunity cost, i.e. lost interest payments from holding stock rather than money[6].

Financial position and windfalls affect the consumption decision in the following way:

$$C_{it}^{intermediary} = \begin{cases} C_{it}^{initial} * 1.25 & \text{if } (W_{it} > \gamma E)\text{and}(V_{it} > \gamma E) \\ C_{it}^{initial} * 0.75 & \text{if } (W_{it} < \delta E)\text{and}(V_{it} < \delta E) \\ C_{it}^{initial} & \text{otherwise} \end{cases} \tag{15}$$

where E is an fixed volume defined as the level of subsistence, and γ and δ are simulation parameters defining how *rich* or how *poor* consumers must be before they start differing from their neighbors. In the following we shall refer to δ as the credit squeeze, i.e. how much do we squeeze debtors in order to bring down their debt, and γ the wealth squeeze, i.e. how much do we squeeze creditors in order to bring down their wealth. Through a tax on labor, all consumers are allowed to consume E - the level of subsistence.

Once the consumption decision is taken, consumers start searching for the desired goods. All consumer goods are homogeneous except for the fact that they are situated at different cells in the two-dimensional consumer space. Consumers can only purchase goods placed in their own or their neighboring cells. A consumer may thus be limited by the availability of goods before C^{final} is determined.

[6]dividend is not necessarily a rate multiplied by the number of stocks held, since dividend payments may depend on the profits of issuing producer.

5.5 Labor Market

Since the money wage is fixed, there are no price changes clearing the labor market. Consumers supply a fixed amount of hours, H, and may or may not be hired for the full number of hours.

Demand for labor is determined by the production decision already described. Producers of consumption goods prefer to hire labor in the areas of the consumer space where they sell the most. Remaining labor, and labor for the production of investment goods is randomly hired.

5.6 Credit Market

The credit market is probably the most simple market of the model, since no banking sector is modeled - the model simply has bookkeeping entries as a clearing device. All agents, producers as well as consumers are provided with a banking account, and all accounts start out at zero. All transactions are registered with both a payer and a recipient, and thus the money accounts always add up to zero. The volume of aggregate money is measured as the sum of all positive money holdings. The interest rate i is a fixed rate.

Producers have unlimited access to credit as long as they stay below a bankruptcy limit, β, which is related to their holding of capital and stock as well as their current level of production:

$$bankruptcy_{it} = \begin{cases} true & \text{if } M_{it} + p_t S_i t + K_{it} < \beta(Y_{it}) \\ false & \text{otherwise} \end{cases} \tag{16}$$

The stock issued by the producer declared bankrupt will loose its value, and only the agents holding this particular stock will bear the burden of bankruptcy. This implies a risk of bankruptcies spreading in the system. With respect to the money debt of a producer declared bankrupt, a credit institution will take the immediate loss. As a compensation an interest differential will be charged on all negative money holdings - until its account balances again. The place of a bankrupt producer will be taken over by a new producer.

5.7 Stock Market

At the stock market consumers and producers buy and sell stock - but only producers can issue new stock. Except for this difference, the behavior of consumers and producers is similar. All stock is treated as homogeneous from the perspective of the trader[7]. Supply and demand for stock is treated symmetrically so that a negative demand for stock, S^d represents a supply of stock.

$$S_{it}^{d\ initial} = 0.5(\frac{M_{it}}{p_t}) \tag{17}$$

[7]In reality stock is heterogeneous, since in the case where a producer is declared bankrupt, the agents holding the particular stock of this producer, will loose it

This initial demand, $S_{it}^{d\ initial}$ is then regulated according to the consumers subjective idea of the current pricelevel of stock. The idea of Keynes that agents have a subjective sense of the *normal rate of interest* is transformed to a *normal level of stock prices* p_{it}^n, calculated as the simple average of the minimum and the maximum price experienced by the individual agent:

$$p_{it}^n = \frac{p_{it}^{max} + p_{it}^{min}}{2} \tag{18}$$

Prices affect the initial decision in the following way:

$$S_{it}^{d\ intermediary} = \begin{cases} S_{it}^{d\ initial} * 0.9 & \text{if } (p_t > 1.1(p_{it}^n) \\ S_{it}^{d\ initial} * 0.9 & \text{if } (p_t > 1.3(p_{it}^n) \\ S_{it}^{d\ initial} * 0.9 & \text{if } (p_t > 1.5(p_{it}^n) \\ S_{it}^{d\ initial} * 0.9 & \text{if } (p_t > 2(p_{it}^n) \\ S_{it}^{d\ initial} * 1.1 & \text{if } (p_t > 0.9(p_{it}^n) \\ S_{it}^{d\ initial} * 1.1 & \text{if } (p_t > 0.7(p_{it}^n) \\ S_{it}^{d\ initial} * 1.1 & \text{if } (p_t > 0.5(p_{it}^n) \\ S_{it}^{d\ initial} & \text{otherwise} \end{cases} \tag{19}$$

Finally the agent takes a bear or bull position based on the windfall gain/loss defined in equation 14. If dividend payment minus losses exceeds the opportunity cost measured by the rate of interest, a bull position is taken.

$$S_{it}^{d\ final} = \begin{cases} 2(S_{it}^{d\ initial}) & \text{if bear and } S_{it}^{d\ initial} < 0 \\ 0.5(S_{it}^{d\ initial}) & \text{if bear and } S_{it}^{d\ initial} > 0 \\ S_{it}^{d\ initial} & \text{otherwise} \end{cases} \tag{20}$$

Behaviour of agents on the stock market both holds stabilizing and trend-following aspects. They only follow trends to the extend that it affects their conception of normal stock prices and their bear/bull position. Apart from that they try to sell high and buy low, thus stabilizing the market.

The stock market is modeled as a linked list of stock through which the agent can search for options to buy or sell, or place options to buy or sell at a reservation price. If an agent gets no response to a placed stock option, he will change the price of the option if he wishes to keep it next time he gets to act at the stock market. p_t is calculated for each period as the average price of traded stock during the last period.

6 Simulation Results

Many different simulations can be performed with the model. A full Montecarlo analysis of robustness has not yet been performed, but in the following we shall present a base run and a number of simulations varying the parameters of this base run.

A few things should be noted on the base run. Parameters have been chosen so that the simulation may run for many periods. Here only 1000 periods are

	Parameter	Value
I	Number of Agents	1800
	Producers of consumption goods	160
	Producers of Investment goods	40
	Consumers	1600
E	Level of Subsistence	50
S	Principal of stock	100
I^0	initial investment	100
ρ	Price of one unit of production capital	100
α	productivity of capital	20
τ	Lifetime of one unit of captital	10
μ	Inverted mark up rate	0.9
H	maximum number of working hours per agent	200
β	credit limit	10
i	interest rate	1%
d	dividend	2%
γ	credit squeeze	5
δ	wealth squeeze	5

Table 1: Parameter Values of The Base Run

presented, but the model may run for longer than that without changing its characteristics. This however is not the case for all possible parameter values. Especially the stock market has a risk of running into and "eternal boom" which will stop the market. As our simulations will show, the model is however stable over a wide range of parameter values.

Another thing to be noted about the base run is the tendency for the model to generate business cycles without there being any fixed upper or lower bound for the turning points. Neither are there any turning points hidden in the decision rules of the model. Thus the cycle may be regarded as an emergent property of the model.

6.1 The Business Cycle

For some parameter values the model generates cyclical patterns. As illustrated by Fig. 3 the cycles appear to be set off by an increase in stock prices which results in increasing investments. With a timelag the boom in stock prices and investment causes a rise in consumption. Stock prices do, however, not increase forever. The supply of stocks (including emission of new stocks) 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 stock 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 stock prices is, however, not all that

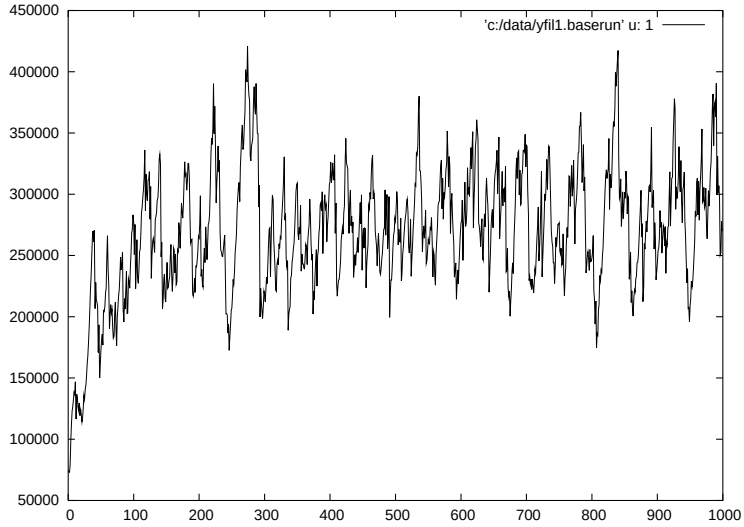

Figure 2: National income in the base run.

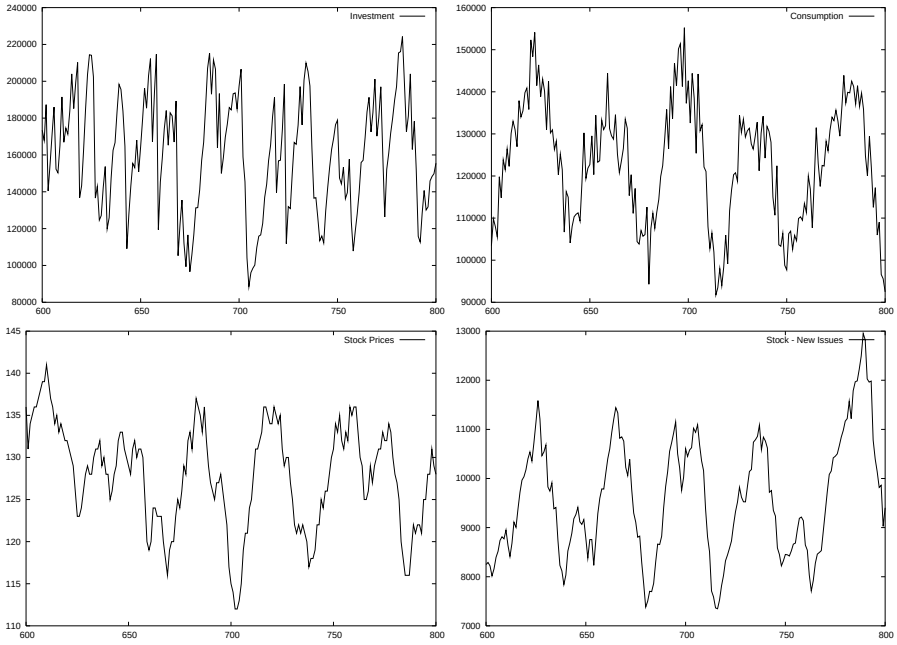

Figure 3: The business cycle(a) investment, (b)consumption, (c) stock price and (d)stock:new issues

obvious. The decision states that agents with positive money holdings will move into holding stocks unless the stock price is high compared to the lowest stock price observed by the agent. Agents with negative money holdings will sell stocks or possibly emit new stocks if they are producers, unless the stock price is very low compared to the highest stock price observed by that agent. For very high stock prices, agents with positive money holdings may choose to sell stocks and for very low stock prices agents with negative money holdings may choose to buy stocks. An additional rule states that agents who have experienced low pay off from their stock holdings (due to lack of dividend or losses from bankruptcies) will be more careful in their purchase of stocks or more ready to sell stocks. These rules should not result in a very volatile stock market, but an stock market that smoothly accommodates economic activity[8]. Further more the behavior of surplus units is approximately symmetric to the behavior of deficit units, and thus there is no built-in tendency for increasing or decreasing stock prices. There is, however, a built-in stabilizer since high prices will stimulate supply and depress demand.

6.2 Squeezing Consumers

The agent-based method makes possible a study of distributional aspects. Here we shall experiment with parameters affecting the distribution of wealth between consumers to learn how this affects the aggregate volumes of our model. The parameters we shall change are γ and δ - the parameters called the *wealth squeeze* and the *credit squeeze*. The credit squeeze δ determines how poor consumers must be before it affects their consumption, ie. before they start consuming less that their neighbors. The wealth squeeze, γ, determines how wealthy consumers are before they start increasing their consumption beyond their neighbors consumption. In the base run both parameters are set to 5, but here we shall vary them from 1 to 10 to see how it affects aggregate production, stock prices, distribution measured by the Gini coefficient[9], and the volume of money.

From a Keynesian perspective one would expect the highest income with a large γ and a low δ, i.e. in a situation where consumers are allowed to build up a large debt before they a forced to cut back on consumption, and where wealthy consumers are forced to spend their wealth on consumption. This is also, what our simulation shows. More surprising is the fact, that we also get the highest Gini coefficient when we force the wealthy to consume, as well as allowing the poor to consume ($\gamma = 10$ and $\delta = 1$). One would expect the highest Gini where wealthy consumers are allowed to build up more wealth and poor consumers are allowed to accumulate more debt.

To explain this, let us have a look at the relation between income and the Gini over the cycle (Figure 5). There is a clear positive relation between income and the Gini coefficient. But what is cause and what is effect? Does income

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

[9]due to the fact that wealth in our model both take negative and positive values, we have had to *normalize* wealth before calculating the Gini coefficient.

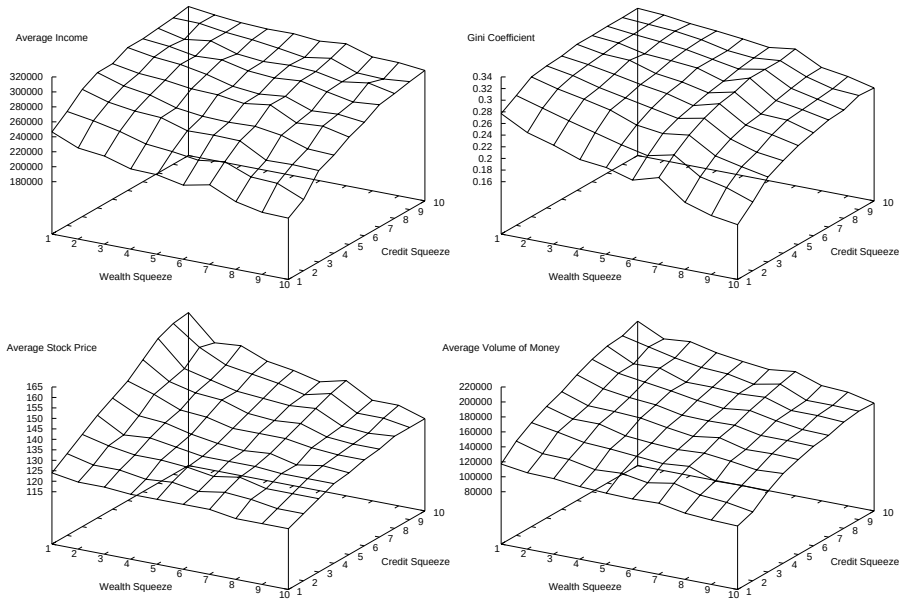

Figure 4: Average over 1000 periods of (a) aggregate income, (b)Gini coefficient, (c) stock price and (d)volume of money.

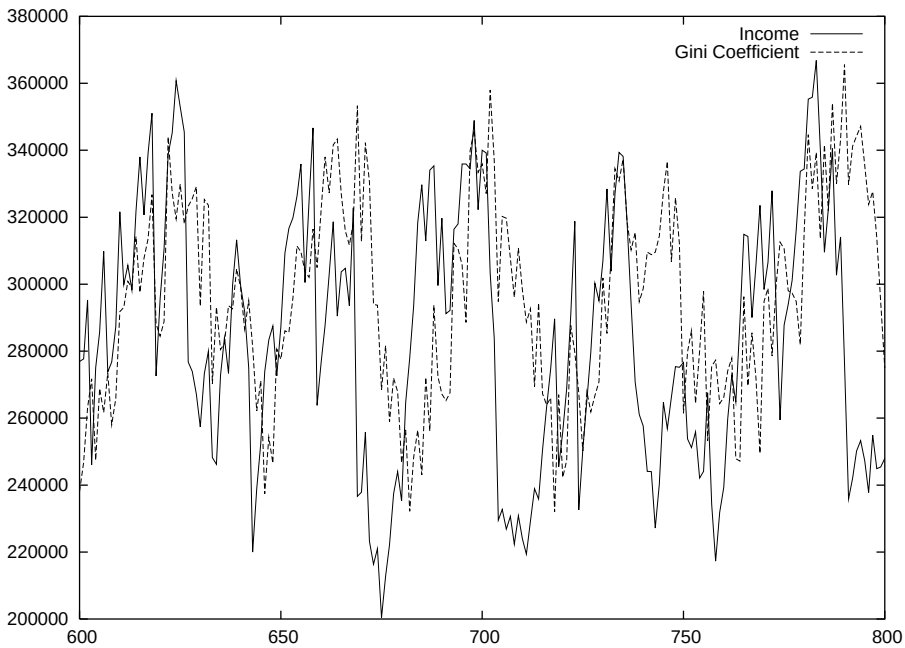

Figure 5: National income and Gini Coefficient (*1 mill.).

increase as a result of the larger differences, or is the larger difference a side effect to increasing income? It is often concluded, that there is a trade-off between income and equality, but with the cycles generated in our model, one cannot talk about a trade-off, since allowing, or promoting increased inequality will not make the system perform better.

6.3 Squeezing Producers

There are several parameters one can vary in order to make it more or less easy for producers to obtain a monetary profit, and thus affect their decision to produce and to invest. Here we have chosen three parameters; the markup rate, the dividend rate and the bankruptcy limit.

The (inverted) markup rate tells us how much of the total output producers will pay out as wages. In the base run we had a markup of 0.9 meaning that producers will keep 10 % of the monetary value of output. In figure 6 we varied the markup rate from 0.8 to 1 with an interval of 0.02.

The dividend rate sets the dividend that producers must pay to the holders of their issued stock. In the base run the dividend rate was set to 2 %. Here it was varied from 0 to 5 with an interval of 0.5.

The bankruptcy limit relates the monetary wealth and the turnover of producers to their monetary debt. A low bankruptcy limit will result in more bankruptcies whereas a high bankruptcy limit will allow producers to accumulate large debts. In the base run bankruptcy limit was set to 10. In figure 6 it was varied from 1 to 20 with an interval of 2.

In general the model behaves very much as expected. The bankruptcy limit does not have very much impact on any of the output data chosen - not even on bankruptcy costs!. Squeezing producers on their markup, on the other hand, has a very big impact on their profits as well as the level of production. Increasing dividend payment has a positive impact on profits as well as production. This may seem paradoxical, but the explanation is to be found in the stock market. The absence of a dividend has a negative impact on the demand for stock, and the resulting low stock prices does not only mean a lower return from issuing new stock, but depresses the whole system. Dividends above 2% however have a negative impact on the system.

7 Conclusion

Our method of analysis has been, first to study the macro-properties of a Keynesian system, and 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 pre-existing stocks of goods, and we did not model relative prices as the central co-ordinator between supply and demand for stocks of goods. By not doing this we have demonstrated

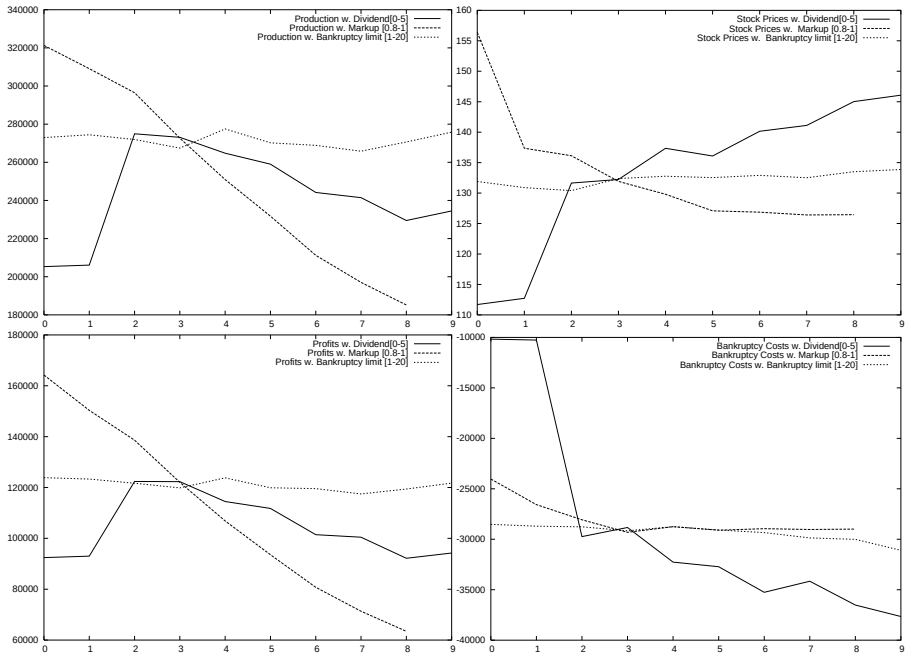

Figure 6: Effect of squeezing producers on a. production, b. stock prices, c. monetary profit and d. bankruptcy losses. All numbers are averages over 1000 periods.

that price changes are not necessary in order for the selforganizing properties of an economy to work. Although our simulated economy does not operate at the maximum capacity level, it is quite stable over a wide parameter space. In some areas of the parameter space, the stock prices have a tendency to boom, in other areas we get regular cycles, or a system that never gets above the level of subsistence. But this is also the case with models that use prices as the selforganizing 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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