The Economy as an Agent-Based Whole -Simulating Schumpetarian Dynamics

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

November 30, 2002

Abstract

As pointed out by Mathews (2002) following the recent special issue of *Industry and Innovation* on Schumpeter's "lost" chapter, "The economy as a whole", Schumpeter's view on the dynamics of economic systems has regained topicality as an early contribution to the complexity view in economics. The aim of this paper is to test some of the ideas of Schumpeter using the agent-based computational model presented in Bruun and Luna (2001). As in the early work of Schumpeter, this model assigns a central role to entrepreneurs, and through mechanisms involving *creative destruction*, the model displays cyclical behavior around a growth path. Inspired by Carlsson and Eliasson's work on Schumpetarian dynamics and economic growth in their framework *the experimentally organized economy* (2002), focus will be placed on the role of the bankruptcy mechanism in selecting winners and exiting losers.

1 Introduction

In his early work Schumpeter had an intuitive idea that the functioning of the capitalist economy, in particular the disturbance caused by entrepreneurs entering the market introducing new products, would generate a growth path with cycles. A development generated by inner forces in the economic system rather than a reaction to external forces. The process generating cycles is also known as a process of *creative destruction*; the economic system must destroy less efficient firms in order to make room for new entrants. In this destructive mechanism another recurrent theme in the work of Schumpeter, namely the credit system, comes into play. The fact that we live in a credit economy where entrepreneurs must enter debt in order to start up production, is what makes the individual entrepreneur vulnerable, but at the same time it is what makes the system strong.

In this sense there exists a schism between what serves the individual and what serves the aggregate economic system. That Schumpeter was very aware of not only this schism but the whole idea of possible schisms between the individual and the system, is particularly apparent in his "lost chapter" (Schumpeter (1912)). Here he notes that *"the entire picture of economic development of a people cannot be represented by a continuously increasing curve which follows a single law. [...]This however does not mean that in the long run there may not be observable a unity of direction in the partial development processes that span the longer time period"*. Or in the words of Carlsson and Eliasson's recent interpretation of Schumpetarian dynamics (2002) *"Economic growth can be described at the macro level, but it can never be explained at that level"*. It can, however, not be explained at a micro level either because, to use a popular phrase, the whole is more than the sum of its parts. Therefore there is no simple relation between the parts and the whole, and in order to understand the whole one must study, not only "the parts", but in particular the interaction of these parts, i.e. the interaction of economic agents.

In the terminology of modern complexity theory this means that economic development must be perceived as an emergent property of economic systems. Whereas Schumpeter could only suggest his cyclical growth path at an intuitive level, we today can attempt to synthetically generate it in computer simulations. Our purpose here is not to study how technological change comes about and generates economic development nor to study what motivates the individual entrepreneurs to accept the risks necessary to start up production. Our purpose is to study the likeliness of entrepreneurial action being synchronized in such a way that growth with cycles appears.

To do this we cannot just study the actions of a single entrepreneur, nor can we treat entrepreneurs as an aggregated group. We need an agent-based computational model where the actual interactions of, not only a group of entrepreneurs but also a group of consumers, can be studied. Consumers are necessary because we need to study the economy as a whole; we need to take into account feed back mechanisms from the macro level to the micro level, and this can only be done by completing the money flow circuit. This is assured by modeling a closed credit system where a debit entry with one agent always has its counter credit entry with another agent.

Whereas we have to be very careful following money flows in the model, we can afford to be more careless when we model the innovative process of entrepreneurs. This is the case since we want to study to what extend Schumpetarian dynamics is due to the structure of the economy as a whole rather than generated by a particular behavior by economic agents. What we need is entrepreneurs who do not have full information on how to fulfill the wants of consumers, but through some kind of experimentation must learn to fulfill these wants by trying out new products. Only by entering debt can the entrepreneur begin to experiment, but he has no guarantee that he will ever succeed. To model this process we shall use the analogy of neural nets learning to respond correctly to *exclusive-or* (XOR) problems.

In their simulation work Carlsson and Eliasson (2002) test the importance of efficient institutions to take care of the exit process in order to secure positive macroeconomic effects of the innovation process. They find negative macroeconomic effects of containing the exit process, i.e. bankruptcies. Inspired by their work we shall experiment with the bankruptcy mechanism in our model in search of an optimal bankruptcy mechanism. These experiments serve both as a test of the models policy-prescriptive capabilities, and as a method for understanding the workings of the credit system.

2 The Economy as a Whole: The Credit Economy

When studying the economic system as a whole the most important factor to recognize is that we live in a credit economy. Schumpeter (1911) complained about the way credit is treated in economic theory, but in the English translation (1934) he points to A. Hahn's "Volkswirtschaftliche Theorie des Bankkredits" as a representative of a new line of economic theory developed after he wrote "The Theory of Economic Development", placing credit in its correct context. Schumpeter's recognition of the work of Hahn helps us interpret what he writes on the nature and function of credit. Rather than perceiving money and credit as mere facilitators of exchange, credit becomes central to the production process, in particular the innovative part of production; *"...in principle no one other than the entrepreneur needs credit - [...] credit serves industrial development"* (Schumpeter (1911)).

In a capitalist economy it is producers who initiate production. Since workers demand money wages, and since producers cannot sell their production before it is produced, producers must hold money in order to start up production. Only by paying out this money as wages can they persuade workers to work for them. As a class producers can only get the necessary money by entering debt.

In the circular flow, Schumpeter's interpretation of the classical static equilibrium state, producers may turn over an unchanging amount of credit, and in this case there is no big difference between an economy using e.g. a stock of gold coins as money and a credit economy. But when there is change, i.e. when a producer wants to enlarge his production, or an entrepreneur wants to introduce new products to the market, credit must be extended beyond the needs of the circular flow. Production can only increase if, in advance of the increase in production, credit has already been extended.

In an economy using gold money, some agents need to save in order to free gold to be lent to investors wanting to extend their production. This implies that in the circular flow, entrepreneurs cannot *force* their way into the market. An agent already part of the system must take a decision to save more in order to make room for an entrepreneur. In this process production has already been shifted from one producer to another, and to explain development in this setting one needs to explain why an agent should suddenly decide to remove demand from at least one producer in order to increase savings.

In a credit economy there is no limit to the credit creating capabilities of the banking sector. There is no input to credit creation and banks will only limit their credit extension due to the risk of borrowers not repaying their loans (Hahn(1920)). Thus in a credit economy an entrepreneur only needs to persuade the banking system to grant him credit in order to force his way into the circular flow - thereby disturbing its equilibrium. This makes it easier to be an entrepreneur and harder to be an established producer in a credit economy, compared to a gold money economy. By *forcing* his way into the production system the entrepreneur challenges all existing producers, and only the best fit producers survive this battle. To explain economic development in this framework one needs to explain why entrepreneurs would want to introduce new products to the market.

The debt entered in order to produce, can only be destroyed if the producers manage to get the money paid out as wages back by selling part of their product to workers. At best entrepreneurs get back all the money paid out, and this may leave them with a real profit, namely the part of their production that they did not sell to workers and did not consume. Only if other sectors in the economy accepts a monetary debt can producers obtain a monetary profit.

That the economy as a whole cannot generate monetary profits implies that the production process of the capitalist system is very fragile. As pointed out by Hahn (1920), *"A modern credit economy is - despite all improvements of liquidity - always illiquid on the macroeconomic plan"*[1]. When firms go bankrupt or when the craving for liquidity increases, banks become less eager to create credit and bankruptcies spread like ripples in a pond. Just as the system is efficient for extending credit and production, it is very efficient for spreading financial problems and assisting the economy in downsizing the level of production.

3 The Economy in Parts: Micro Dynamics

As already mentioned we have no ambition of contributing to the theory of micro dynamics or innovation, but in order to understand the interaction between microunits and the macrosystem we need some way of modeling entrepreneurial activity. Studying the framework of credit economies we have learned about its potentials and its weaknesses, but to understand how capitalist production systems takes advantage of its strengths and deals with its weaknesses we need to make some assumptions as to how producers and entrepreneurs act.

To study the credit economy we must have some producers that take production decisions and carry them out by borrowing money and spending the money on hiring labor. Producers must have a way of getting back the money paid out as wages, and this is done by selling goods to the workers. Since we want to model a growth process including entrepreneurial dynamics, we must, in the terminology of Carlsson and Eliasson (2002) model entrepreneurs who

[1] My translation.

need to experiment in order to satisfy the wants of consumers. Statespace must not be so limited that it is immediately explored by intelligent entrepreneurs. Still we want to keep things very simple. It is more important for us to have an entrepreneur that we can understand and control, than it is for us to model an entrepreneur that the real world entrepreneur could identify with.

Following Luna (1999) we model production units as single-layer neural networks with two input neurodes and one output neurode (see figure 1). These production units learn by experimentally changing the weights of their neural nets. Then we confront the production unit with a learning problem that is too complex to be learned by such a single-layer neural net. *Exclusive-or* (XOR) problems (also known as inequivalence) have this nature, i.e. they are not linearly separable. At the same time they are so simple that they can easily be learned if two production units combine into a two-layer neural net (Holland (1998)).

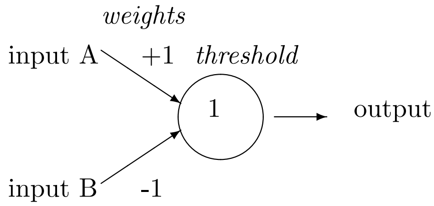
Independent production units only respond correctly to XOR problems by chance i.e. they are ineffective[2]. To become effective firms, production units need to cooperate. This is modeled by letting the single-layer two-input neural nets combine into multilayer nets. In principle, as demonstrated in figure 1, it only takes a combination of two single-layer networks to solve the XOR problem, but in the simulation, the firm constellations will often be larger as a result of learning. Until the network is fully trained, the entrepreneur will continue to attract new workers, rather than training just the one worker that is necessary in principle[3] .

By using this analogy we get a precise definition of effective firms and their efficiency. An effective firm is a conglomerate of individual production units that have learned to respond correctly to XOR problems. A firm is established at the initiative of an entrepreneur. The efficiency of the firm is determined by the number of production units employed to form the trained network. A small firm can produce just as much as a big firm, and thus the social optimum is found when all firms are made up of two production units, i.e. the minimum it takes to learn the problem.

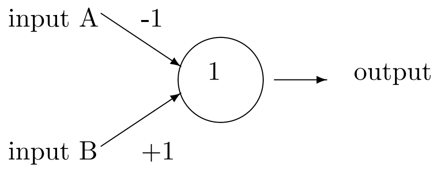
[2]For the four possible instances; {A,B},{not A,B}, {A, not B}, {not A, not B}, the responses {False, True, False, True}, satisfies the XOR function, and this is how production units should respond to demand signals. As can be read from the tables of figure 1, neither of the two single-layer neural nets will respond correctly to all possible combinations of A and B.

[3]The argument for this being that the entrepreneur is not aware of the structure that needs to be learned; he merely responds to the satisfaction of his customers.

Two independent neural nets and their output



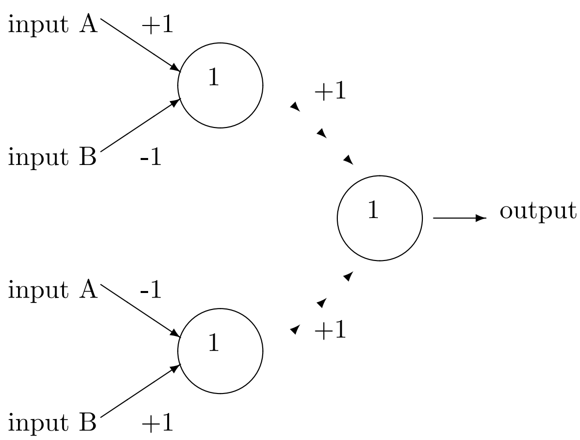
A	B	Output
0	0	0
0	1	0
1	0	1
1	1	0



A	B	Output
0	0	0
0	1	1
1	0	0
1	1	0

The inputs are weighted, and the sum of the weights determine whether the threshold is reached. If the threshold is reached output is 1, otherwise it is 0.

Two Neural nets combined to solve *exclusive or*



A	B	Output
0	0	0
0	1	1
1	0	1
1	1	0

Figure 1: Neural networks

4 Schumpeter and Agent-Based Computational Economics

At the time of Schumpeter's writings, the *"development processes internal to the economy"* that he wanted to study, could in practice only be discussed and analyzed verbally. As is also reflected in the work of Schumpeter, economics was beginning to adapt the causality concept of Mach and the idea of general interdependency, but the notion of development could only be captured as movements toward an equilibrium. Today, given the immense computational capacity of modern computers, we have a number of different methods for studying dynamic processes. Here we shall argue that the methods of agent-based computational economics (ACE) are well-suited for the analysis of Schumpetarian dynamics.

As a declared new approach to economics, ACE was started in the midnineties by a group of economist wanting to study evolutionary processes in at "bottom-up" fashion[4]. Model techniques and inspiration came from the *artificial life* community, and thus the idea was to understand economic processes by artificially creating them. Rather than trying to capture the processes in focus by mathematical functions, ACE wanted to let a large number of autonomous agents interact *in silico*, thereby allowing for well-known processes or macrophenomena to emerge as outcomes of the interactions.

An important feature in agent-based models is that causality does not merely go from the microlevel to the macrolevel; feedback effects from the macro level to micro units are just as important. One may also say that these models are microfounded as well as macrofounded. Properties at the macro level that feed back to the micro units may be institutional features purposively built into the setup of the system, or they may institutions emerging from the simulation of the model. An example of a built-in feature is the accounting system of credit economies. An emergent property may be the emergence of a medium of exchange or the emergence of business cycles, that will have an impact on the way individuals behave.

An analogy often referred to in agent-based modeling is the ant colony (Holland (1998). It is very hard to deduce e.g. the existence of anthills from studying individual ants. Looking at the average behavior of ants and summing up with an estimate of the number of ants will get us nowhere. Only be describing the behavior of ants in a set of simple decision rules and letting a large number of these "artificial ants" interact, have researchers come to understand how ant colonies are organized. Ace researchers hope to reach a similar level of understanding with the economy as the object of study.

In order to carry out this task, agents are provided with a set of decision rules that determines their behavior. Decision rules are typically formulated as a set of `if-then` statements, and may evolve through some kind of learning mechanism, or they may be static. Rules may evolve by changes in parameters, or they may evolve more fundamentally through changes in their structure. Depending on the purpose of the model, decision rules may be very simple or very complex. If the purpose is to study the macro properties of a system, simple decision rules is typically the best choice, whereas more complex rules are called for, if the point of interest is the way agents respond to their environment.

ACE modelers are forced to take into account the concepts of time and space.

[4]The notion of Agent-Based Economics (ABE) and later Agent-Based Computational Economics (ACE) can be traced back to a workshop at UCLA 1995 (`http://cce.sscnet.ucla.edu/`).

In a simulation model everything cannot happen at once; processor time has to be split between agents. The assignment of processor time to agents typically takes place by picking agents one by one, randomly or in a determined order, and allowing them to act in accordance with their decision rules[5]. When an agent has "acted", changes in his parameter values are not necessarily made visible to other agents immediately after the action has taken place. Whether the updating of agents take place sequentially as the action, or whether it takes place in parallel, thereby pretending that all agents have acted at the same time, is a widely discussed question, since the choice can have substantial consequences for the results of the model (Huberman and Glance(1993)).

Just as everything cannot happen at the same time, it will often make things more complicated if the modelers insists on letting everything happen at the same space. Further more the ability of dealing with the concept of locality is one of the strengths of the approach. Agents of a given system need not have information about the whole system in order to act in such a way that an optimum for the system as a whole is reached. By only allowing agents to react to local information, the system is still efficient in finding an optimum[6]. Imposing a spatial structure on a model may have a very specific theoretical motivation, or it may be motivated in the desire to make the model more realistic by restraining the information of agents to a local area[7]. To deal with the concept of space, agents are often placed in a particular spatial construct. Since cellular automata are one of the founding techniques of ACE, cellular structures[8] are still widely used within ACE model.

By such differences in time and space between agents, they become exposed to different realities and different conditions. If agent `X` has bought the good placed at cell `(i,j)` at time `t`, then agent `Y` will not have the chance of purchasing that good when he visits cell `(i,j)` at time `t+1`. This is also what makes it sensible to talk about autonomous agents in a simulation model. Although agents may start out being exactly identical, they go through different historical developments, and the exact historical conditions they have been exposed to influence the decisions the make. They live their own lives, and once simulation time is running, their histories are out of the hand of the model builder.

For Schumpeter's ideas about development where *the whole is more than the sum of its parts*, agent-based computational models are particularly useful. This is the case because the schism between parts of the economic system and

[5]ACE models may also make use of parallel processing, or the more recent development of multithreaded programming.

[6]In model setups where an optimal solution may be found analytically it is found that agent-based models are not always good in finding *the* optimum, but very efficient in getting close to the optimum.

[7]An example of a theoretical motivation for imposing a spatial structure can also be found in Schumpeter's work (1911), *"needs and their visible satisfaction immediately lead to a contagious effect on the economic agents in the vicinity"*. In Bruun(2000) such a neighbor effect in consumption is implemented in an ACE model. Space can also be used in order to force agents to search, e.g. for food (Axtell and Epstein (1996)).

[8]The kind of cellular structures discussed here may be thought of as checker boards where edges are connected (i.e. turned into a doughnut) so that all cells have the same number neighbors.

the economy as a whole may actually be modeled. As we have learned from agent-based models, we need no longer rely on intuition to understand how the whole may live a separate life from its parts. The central concept is emergence, i.e. the fact that the aggregate system, generated by the interaction of its parts, may display behavioral patterns that cannot be deduced by studying its parts.

In *"The economy as a whole"*(1912), Schumpeter is very close to formulating the phenomenon of emergence when he discusses the third general principle of development; that *economic development is not an organic entity that forms a whole*. Schumpeter also emphasize that behavior cannot be treated at an aggregate level. We may find patterns and regularities at the global or macrolevel without being able to identify them at a partial level, and such patterns are only understood, if we learn how they emerge.

From a Schumpetarian perspective, another attractive characteristic of ACE models is that the interaction between agents generate so complex behavior that even apparently very simple models may "run" for ever without ever reaching a stationary state. Further more it is not unusual to observe surprising new patterns emerge after thousands of simulation periods, although there has been no changes in external conditions. Thus agent-based models could have provided Schumpeter with a method for proving to the profession that it does make sense to talk about economic development as something more than the response of the economic system to some external event. Economic development may be internal to the economic system.

5 The Simulation Model

The simulation model applied for studying Schumpetarian dynamics is an agent-based model developed in order to describe an endogenous growth path generated by learning on the production side (Bruun and Luna (2001))[9]. A number of agents (40*40)[10]defined by their ownership of a banking account and organized in a cellular space, is modeled both a set of decision rules determining their behavior as consumers and a set of decision rules determining their behavior as producers. As consumers the agents can push around their shopping cart in the cellular space, searching for producers that can fulfill their wants. As producers, or production units, agents cannot move and must learn how to respond correctly to consumer demands placed on their cell. All agents are born the same except from a random assignment of weights in their neural network and a random placement of shopping carts.

Production units are modeled as single-layer two-input neural networks as described in section 3. As production units, agents can take 4 different states; They can be independent production unit that respond to consumer demands

[9]The model is written in Swarm (`www.swarm.org`) and may be downloaded at:`www.socsci.auc.dk/˜cbruun`.

[10]Many of the parameter values referred to in this section (e.g. number of agents and the wage offer of entrepreneurs) are default values that may easily be changed in the simulation model.

as well as they can on their own. They can become entrepreneurs hoping to increase their success rate by hiring one or more of their neighbors, or they can become a worker by letting a neighbor hire them. Finally an entrepreneur that successfully learns how to respond to consumer demand, i.e. *read* the signals of consumers, is called an effective firm.

Production units are present in the market all the time in one of the four different states. However, we can still talk of entry to the market when a new firm is established and exit from the market when a production unit is declared bankrupt. A firm is established when an independent production unit turns into an entrepreneur by hiring another production unit to work for him. Exit from the market happens primarily through a bankruptcy mechanism[11]. After a bankruptcy the production unit is "reborn" with a cleared banking account and a new random assignment of weights in his neural net. Workers of an entrepreneur declared bankrupt will continue their existence as independent production units.

All independent production units will observe how their neighbors are doing, and period for period build up confidence in them according to how they are doing. When confidence in a neighbor reaches a certain threshold, the production unit will turn into an entrepreneur an try to hire that particular neighbor.

An entrepreneur trying to establish an effective firm may hire just one of his eight neighbors, or he may end up hiring all of his 8 neighbors. How large a firm ends up being depends on the speed with which the neural network is trained, and on how large the entrepreneurs confidence in other potential workers is. As long as his neural network is not fully trained, the entrepreneur will search for additional workers.

All production units have a *shopping cart* that they, in their role as consumers, can push around the cellular space of production units in search for a production unit that can satisfy their demand signals. A demand signal is a set of `input A` and `input B` as described in figure 1, and the response desired by consumers is the response of the two-layer *exclusive or* network in figure 1. If response to a demand signal is not correct, the shopping cart will move to another cell at random. If the shopping cart stops at the cell of a worker, demand signals are transferred to the entrepreneur who hired the worker. Once a consumer has found an effective firm, only a *mutation move*[12] can make him disappear from the cell again.

In the beginning of a simulation where there is only a few effective firms, and following a lot of random movements of shopping carts, there is an advantage in being a big firm, simply because the larger number of cells occupied by such a firm will function as tentacles catching consumers. In the longer run disadvantages of being a big firm will however outweigh this advantage.

First of all there is no limit to the production capacity of either an inde-

[11]There is a small mutation rate for unmotivated dissolution of firms. In models where experimentation is part of the optimization technique, mutation is often used in order to prevent the system from locking itself into a suboptimal position.

[12]In this case mutation is a small possibility that a consumer will make an unmotivated move to another cell.

pendent production unit or an effectively established firm. They will attempt to respond correctly to all demand signals received - but will only receive payment for the signals to which response was correct. There is no cost per signal response; the only production cost is labor which is paid per period independently of the number of demand signals received. From this it follows that, as the number of random moves goes to zero, the income of an entrepreneur will be independent of the number of workers, whereas the production costs are a positive function of the number of workers.

Prices in the model are fixed, the price of having a correct response to a posed demand signal being set to one. Wages, however, are negotiated between the entrepreneur and the worker. The last negotiated wage will be the wage of all workers in the same unit, but there is no process ensuring equalization of the wage level between firms. When wages are negotiated, the entrepreneur will calculate expected earnings, defined as the number of successfully answered demand signals, by finding the average earnings per member before hiring another worker. The new worker is expected to contribute an equal sum, and this is his wage offer[13]. In the same way the potential new worker sets his reservation wage at the level of his own earnings as an independent unit in the previous period. This wage setting implies that an independent production unit that, by pure chance, has been successful on his own, is more likely to end up as an entrepreneur since he will offer a high wage, and less likely to end up as a worker since he will demand a high reservation wage.

The entrepreneur must cover the cost of training the network. He must pay his workers a fixed wage whatever his earnings are. However, he cannot expect earnings to increase until he has trained his network, i.e. learned how to respond correctly to demand signals. Even after his network has been trained the entrepreneur may run into financial problems. He may have estimated earnings too high and thus offered a wage to his workers that is too high compared to earnings. The entrepreneurs thus run a large risk of bankruptcy.

For the individual agent, consumption is a declining function of wealth, inspired by the empirical work of Clower and Johnson (1976). The consumption function of Clower and Johnson is modified in order to assure consumption out of a negative wealth, and is combined with a minimum subsistence consumption of unity. Because production units and consumption units are combined as agents, consumption out of a negative wealth is necessary in order to get the model going. If nobody is willing to enter debt in order to consume, the economy will never take off.

Economic activity takes place in a credit system where all agents are assigned a banking account with overdraft facilities. When the limits of the overdraft facility is crossed, the agent is declared bankrupt, and the loss is equally split among all remaining agents. This bankruptcy rule, which was chosen since the model has no direct contracts between individual borrowers and lenders, lends stability to the system, since it minimizes the risk of chain bankruptcies[14].

[13]See Bruun and Luna (2001) for simulations with a less generous wage offer.

[14]See Bruun(2000) for an ACE model with direct contracts between borrowers and lenders.

Combining the fact that there is no limit to the production capacity of effective firms with the fact that all wages and profits of production units are immediately transferred to their other self; the shopping cart, means that the level of production in the system is very elastic. Consumption will generate wages and profits and wages and profits will stimulate consumption. This makes the level of production very dependent upon the distribution of wealth in the system, a very skewed distribution of wealth having a negative impact on the level of production.

6 Schumpetarian aspects of the model

Although not purposively developed as a Schumpetarian model, the model has several Schumpetarian aspects. The most important aspects have already been discussed. First of all the model has entrepreneurs who try to establish effective firms in an uncertain environment. Some entrepreneurs are successful, others are not. Secondly we are dealing with a credit economy in which entrepreneurs must enter debt in order to start up production. The credit system is a closed system with no exogenous money, i.e. all monetary positions add up to zero.

There are also aspects important to Schumpeter missing in the model. Aspects as interest rate and changing price levels which Schumpeter probably would have thought were essential for the emergence of the business cycle. In the process that Schumpeter described, the entrance of new entrepreneurs would cause changes in profit rates, interest rates and price level, and these changes in what pushes other producers out of the market. Our process is much more simple, but the results are, as we shall see, similar. In this context we find it more important to reproduce the main ideas of Schumpeter by as simple means as possible, rather than making exact reproductions of his thoughts.

The most important critique of the model from a Schumpetarian point of view is the static nature of demand, and thus of the learning problem of the producers. To put it in the terminology of Carlsson and Eliasson (2002), the state space is limited although it is non-transparent to the individual production unit. With the learning problem being fixed, there is a limit to endogenous growth. For growth to continue, one could imagine that more complex demand signals with a higher pay off would emerge, either from the demand or the supply side, and cause a new learning process by producers. There is, however, also advantages in using a fixed learning problem as a first approximation of a Schumpetarian world, since it allows us to study the efficiency of the learning process and the impact of learning on the system.

7 Simulation results

For a wide range of parameter values the model displays cycles around a marginally declining growth path. The growth path is due to learning by producers; as entrepreneurs manage to establish effective firms, production increases. Since it

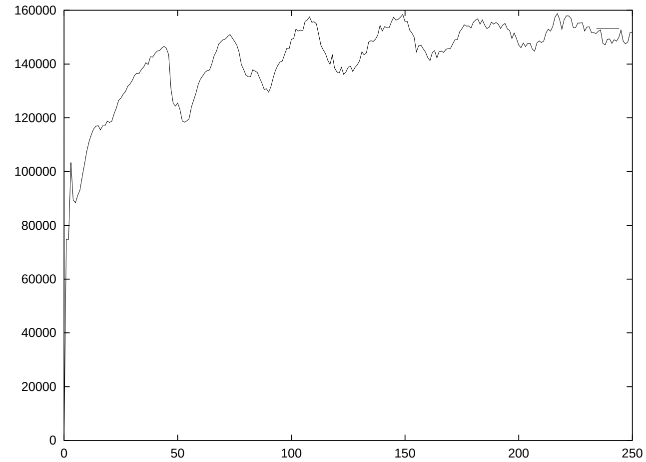


Figure 2: Production over time (250 periods).

is a static learning setting, i.e. what needs to be learned does not evolve over time, growth stops when no more effective firms can be established[15].

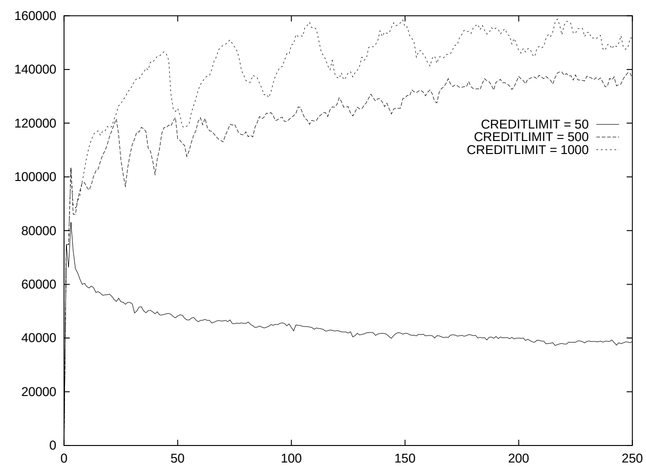


Figure 3: Production over time with 3 different credit limits

Why the cycles emerge is a more difficult question to answer. It is, however clear, that the bankruptcy rule plays an important role in generating cycles. As demonstrated in Bruun and Luna (2001), cycles are completely absent if e.g. a public sector take all losses due to bankruptcy without imposing a corresponding tax on the system. If we study the simulations presented in figure 3, 4 and 5 it is also clear, that the cycles in production peaks together with the volume

[15]In a state where the number of firms cannot grow, individual firms may still go bankrupt freeing resources for the establishment of a new firm.

of credit. As was also suggested by Schumpeter, there is a build up of credit in the upturn when entrepreneurs need new credit to enter the market, and destruction of debt in the downturn where efficient firms repay their debt and inefficient firms go bankrupt. Upper and lower turning points can, however, not be predicted from a study of the model, and we may therefore think of the cycles as an emergent property of the system.

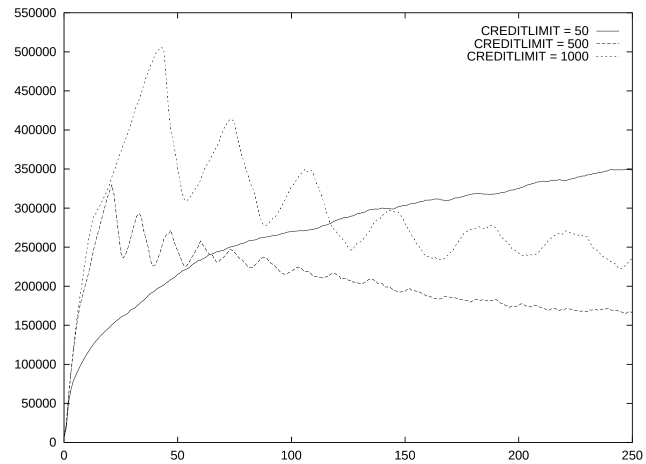


Figure 4: The volume of credit over time with 3 different credit limits

Another interesting thing to notice is that in the long run the volume of credit falls as the volume of output increases (figure 4), except in the case with a very severe credit limit of 50 where the direction is exactly opposite. An economy that is close to reaching a steady state does not need as much credit as an economy in which a lot of adaptation is still going on. It is friction that creates a need for credit.

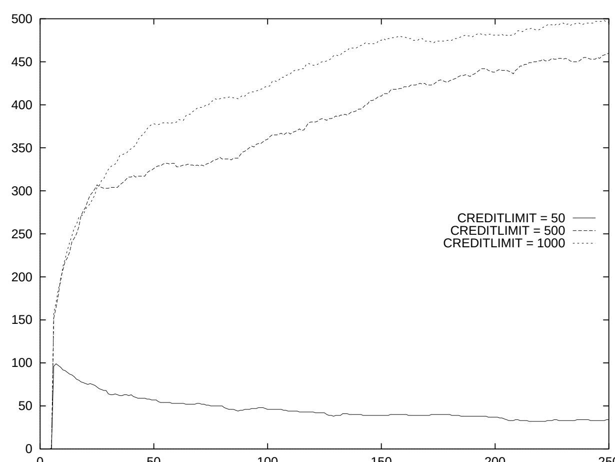


Figure 5: Number of effective firms over time with 3 different credit limits

From a Schumpetarian perspective, the results from simulating the model demonstrates that business cycles is a phenomenon that may emerge endogenously by very simple means. It may surprise even Schumpeter if he could witness how easily cycles emerge in economic systems. Just as biological systems have a tendency to produce cycles so apparently do economic systems[16].

8 Finding the optimal bankruptcy limit

According to Carlsson and Eliasson (2002) an important task for economics is to find the institutions that, on the one hand will help potentially successful entrepreneurs succeed, but on the other hand will not allow inefficient production units to survive. Picking the right institutions may have tremendous importance for the growth rates of an economy. In an agent-based model such a problem can be addressed directly. In the presented model the relevant institution to address is the bankruptcy rule. How large should the overdraft facility of the individual production unit be in order for the economy as a whole to perform optimally?

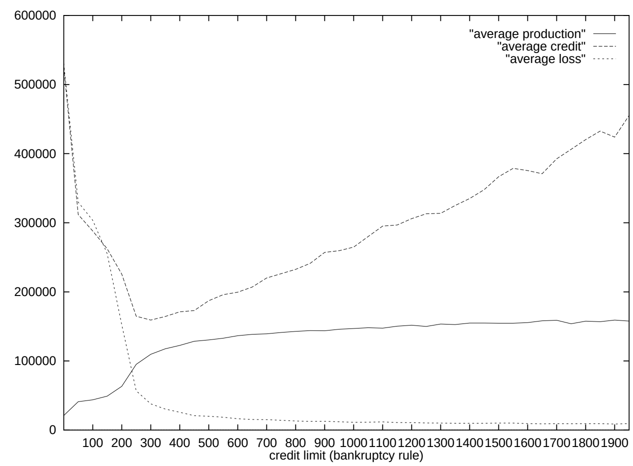


Figure 6: Production, Credit volume and loss with changing credit limit (average over 500 periods).

By varying the bankruptcy limit we get a pretty clear indication of the optimal bankruptcy limit for this model. With a bankruptcy limit around 500 we are close to the optimal level of production, losses are relatively small (small cost of using the credit system), the credit volume is relatively low, and perhaps most important from a Schumpetarian perspective, the average firm size is at its minimum, indicating very efficient firms (see figure 7).

[16]Other examples of emerging cycles in economics can be found in Bruun(2000) and Epstein and Axtell (1996)

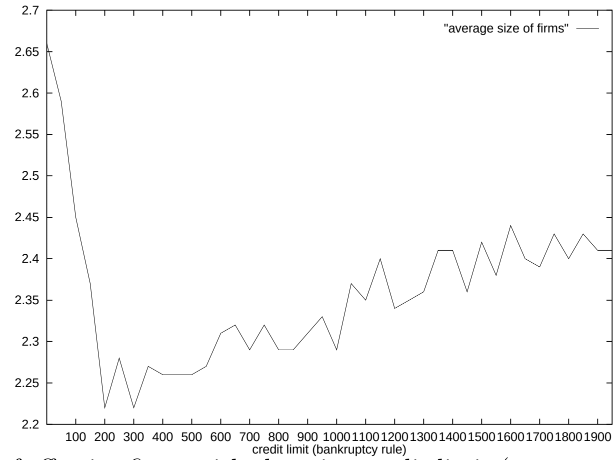


Figure 7: Size of effective firms with changing credit limit (average size over 500 periods).

If we lower the credit limit production will fall, and losses will reach extreme heights. The few effective firms that are actually created in this environment, are less efficient than the firms created with a larger credit limit. In other words we have an economy that is prevented from "taking off".

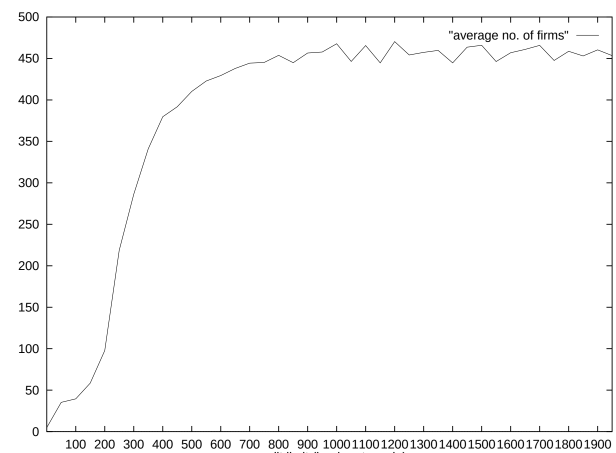


Figure 8: Average number of effective firms (over 500 periods).

If, in stead, we raise the credit limit, we get an aggregate level of production that is a little higher, but it comes at a price. A higher credit volume may be perceived as a cost, although in our model it comes for free. More importantly the average firm becomes less efficient. In the terminology of the model, more labor hours than necessary are spend producing the output.

Above we have only used averages over the simulation period. To see how changing the credit limit effects the development of the economy, we must return to figures 3, 4 and 5, where we have chosen 3 different credit limits (50, 500 and 1000) to see how they differ. It is interesting to note how changing the credit limit affects the amplitude and frequency of the business cycle. A lower credit limit means more but smaller cycles since less debt is allowed to build up before bankruptcies *clear the air*.

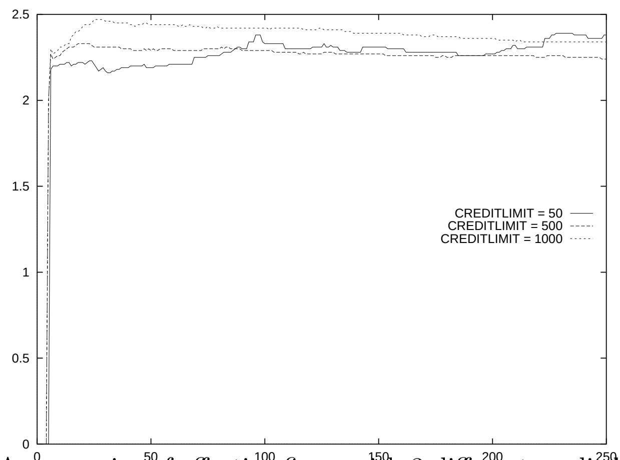


Figure 9: Average size of effective firms with 3 different credit limits

Looking at the efficiency of firms (figure 8) in these three simulations, we may observe that during the first 80 periods a tighter credit limit does enforce more efficient firms, but it comes at a very high price since only a very few effective firms are established, and the economy performs very poorly. The few firms that are created manage to build up a large fortune thereby forcing the rest of the agents into debt that is constantly turned over in the system by bankruptcies. This results in a larger credit volume than for simulations with a more liberal credit limit.

9 Concluding Remarks

The agent-based endogenous growth model presented here may be perceived as a simplified version of the project outlined by Carlsson and Eliasson (2002). The strength of the model is that it in a very simple and rigorous way manages to deal with many of the concepts introduced by Carlsson and Eliasson in their work on Schumpetarian dynamics. The weakness of the model is that the state space is limited and following from this it has a declining growth rate.

The simulations do support Schumpeter's claim that the dynamics following from entrepreneurs entering debt to enter a market, is likely to exhibit cyclical movements. This is important information, not only for understanding how the economic system works, but also for understanding how we can develop institutions that promote growth. As an example our simple experiment tells us that we should be careful in picking the right credit limit for firms.

We feel confident that the most important factor in generating business cycles is to be found in the structure of the economy, rather than in any particular behaviour by economic agents. When entrepreneurs have a tendency to swarm, the reason should not be searched for within the group of entrepreneurs, but rather in the external conditions they are faced with, i.e. their interaction with the economy as a whole.

Our experiments with the bankruptcy limit does not directly confirm the results of Carlsson and Eliasson (2002) that containing the exit process has negative macroeconomic effects, if these macroeconomic effects are taken to be the average level of production. This however is due to some of the simplifications in the model presented here. The large built up of credit when the bankruptcy limit is loosened, is not allowed to have any negative effects in our model. If there was a cost related to credit, e.g. an interest rate or if there was a production limit beyond which prices were allowed to increase, one would expect negative effects on the level of production.

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