Multi-Agent Simulation of Fund Circulation in an Artificial Economic System Involving Self-Adjusting Mechanism of Price, Production and Investment

Shigeaki Ogibayashi *, Kousei Takashima **

* *Chiba Institute of Technology, ogibayashi@sea.it-chiba.ac.jp*
**Hitachi Information Systems, LTD

Abstract

An artificial economic system composed of producers, consumers and a bank was modeled and macroscopic behavior of the system was simulated based on microscopic rules of acts of each agent, where it was assumed that the consumers buy products within the limit of their disposable income, selecting the cheapest product in the market, and producers hire consumers, pay them salary, feed products to the market adjusting both the amount and price of products based on both their amount of goods in stock and total sales during some periods and sometimes invest in equipment, borrowing money from the bank.

As a result, it was revealed that the calculated macroscopic behavior of the artificial economic system shows in good agreement with that of a real system in that the market price tends to an equilibrium price depending on the supply and demand of products in the market, two types of producers, winners and losers, arise depending on the production cost with some of the losers ending up going bankrupt, and a business cycle emerges through the fund circulation among agents where total deposit and loaned money in the bank showed cyclic up and down movement in time.

1. Introduction

Multi-Agent Simulation is widely used in recent years to analyze the macroscopic behavior of social systems based on microscopic rules of acts of agents which are independent actors in the specific system under concern. Previous research works [1-3] in this field have dealt with various problems in social system such as epidemic disease, community problem, problem of social gap in wealth, marketing problem, etc. Since many of the social problems relate to an economical aspect, it seems important for social system models to involve fundamental economical aspects. However, few of previous reports have tried to construct a model which involves fundamental economic behaviors such as a self adjusting mechanism of price and production in the market and business fluctuations with boom and recession, etc.

This paper presents a multi-agent model for a fundamental economic system which involves self-adjusting mechanism of price, production and investment, in order to construct an artificial economic system with realistic behavior.

2. Simulation model

It is assumed that an artificial economic system is composed of consumers, a bank, and three types of producer including retailers, wholesalers and an equipment maker. Macroscopic characteristics of economic systems such as market price of products, total amount of products supplied or purchased in the market, total deposit and loaned money in the bank, fund circulation etc. are considered to be generated as a result of the interaction between the actions of these agents.

The microscopic rules of action of agents are defined as follows so that it is simple and essentially close to those of a real system.

Consumers are assigned to one of the producers for working, get wages, and buy several kinds of products according to their utility function with their disposable income, selecting the cheapest product in the market for each kind of product. Each consumer has a bank account, deposits a part of wages and withdraws money before the purchasing action at every fiscal period. The disposable income is defined as the wages plus withdrawn money from the bank account at every fiscal period. The wages are composed of a fixed salary which is given randomly between lower and upper limits and a bonus which is given when surplus money exists for a producer after paying the fixed salary.

Producers hire consumers as employees, pay them wages, make production plans, produce products, supply the products to the market, and deposit and withdraw money in the bank at every fiscal period. In production planning, producers decide both the amount and price of each kind of product for the next financial period, where the amount is decided based on both the

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amount of goods in stock at the end of the previous period and total sales during 10 periods in maximum of previous periods. In price adjustment, flag numbers for increasing or decreasing price are added or subtracted by one, based on both the amount of goods in stock and the estimated proper amount of production at the end of previous period, and the price is increased or decreased by 5% when the flag number reaches a critical number. A lower limit of price is assumed to be production cost.

In addition, retailers buy raw materials supplied by wholesalers. When raw material is short, the amount of production is limited by the amount of raw material available. Retailers also have a bankruptcy rule where a retailer quits production of certain kind of products when they are all unsold for 20 periods. The producer goes bankrupt when he quits the production of all kinds of products. Retailers and wholesalers invest in equipment to increase their production capacity by buying equipment from the equipment maker when their production amount reaches the upper limit of production which is initially given randomly and increased by 1.5% after the investment.

The bank keeps surplus money of consumers and producers in their bank accounts and lends money to producers according to their demands for investment with the interest rate of 1%. The lent money is paid back constantly by the producers in 120 fiscal periods. At bankruptcy, the retailer pays back all loaned money, and if it is more than the available money of the retailer, it becomes a nonperforming bond and total assets of the bank are reduced by that amount.

3. Simulation method

A simulation program has been constructed using Microsoft Visual C++ with object oriented programming, where agents such as consumers, etc. are represented as objects programmed as instances of classes. Total system as a market is also represented as an instance of a class which includes above mentioned objects.

Three types of simulations have been performed in the present study. The simulation conditions are given in Table 1.

First one is C-R simulation where consumers represented as C and Retailers represented as R are assumed to be only agents in the system and equilibrium mechanism in price is simulated by changing the condition of determining the amount and price of products in production planning at every fiscal period. Here, initial price of products is determined as triple of the production cost which is given randomly, the upper limit of production is not set, and disposal income of each consumer is assumed to be constant

and assigned randomly. Investment and bankruptcy are neglected.

Second one is C-R-W simulation where wholesalers represented as W are added to confirm the effect of wholesalers in the simulation. Here, the disposal income of consumer is assumed to come from the wages paid by producer, upper limit of production for wholesaler is set and changed with 4 levels. Investment is neglected, but bankruptcy is taken into account.

Third one is C-R-W-E-B simulation where equipment makers represented as E and a bank represented as B are included in the system and investment actions of R and W are taken into account. Here, producers deposit surplus money in the bank and borrow money as short-term loan when their money at hand becomes short. Wages paid to employees are composed of constant wage and variable one called bonus, the latter is paid when surplus money for the producer exists after paying all expenses. The borrowed money at the investment is a long-term loan and constantly paid back in 120 fiscal periods.

Table 1 Simulation conditions.

Agents included	C,R	C,R,W	C,R,W,E,B
No. of C	10	100	100
Initial wage of C	6000~24000 in random	4000~8000 in random	4000~8000 in random
No. of R	3	10	10
Initial price of R	Random	Random	Random
No. of product kinds of C	3	6	6
Wage paying rule	———————	With bonus	With/without bonus
Production control rule	With	With	With
Short-term lending rule	———————	———————	With/without
Investment rule	———————	———————	With/without
Price control rule	With	With	With
Bankruptcy rule	———————	With	With/without

4. Simulation result

4.1 C-R simulation

Calculated results of average price and number of products supplied or purchased in the market are shown in Figure 1 as a function of fiscal period where the determining rules of both price and amount of each kind of products are applied. Here, it should be noticed that the total demand of consumers is constant because the disposal income of consumer is assumed to be constant. Under this assumption, as shown in Figure 1, average price level is high and the amount of products purchased is much lower than the amount of products supplied in the initial stage of calculation. However,

the price and the number of products supplied or purchased tend to equilibrium levels in the final stage of calculation. This result shows that the present model involves self-adjusting mechanisms of both price and amount of production, although it takes more than 400 periods for the equilibrium states to be attained, the reason for which is that the demand of consumers is assumed to be constant. When the disposal income of consumer is assumed to come from the wages paid by producer, the price and production amount achieve equilibrium in the very early stages of calculation as shown in Figure 2 in next section. The reason for it is considered that the total demand is dependent on the profit of producers as in a real system.
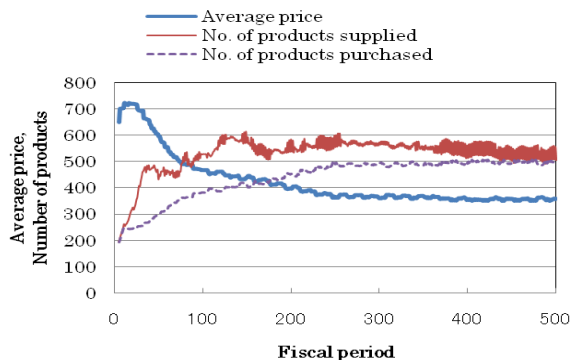

Figure 1 Change in the average price of products in the market and number of products supplied or purchased.

4.2 C-R-W simulation

When wholesalers are included in the system, retailers buy raw materials supplied by wholesalers. In this case, the amount of production by retailers could be limited by the amount of raw materials in the market when they are short compared with the demand by retailers.

The calculated average price of products of retailers is presented in Figure 2. It is noted that the average price comes in equilibrium soon after the start of the calculation. A similar tendency is also observed in the case of the number of products supplied by retailers. It is also noted in Figure 2 that the equilibrium value of price is greater when the upper limit of production of wholesalers is as small as 300 or 400. This is because the numbers of products of retailers supplied depends on the upper limit of production of wholesalers. It is also found that when the upper limit of production is assumed to be 300, some of the retailers go into bankruptcy during the fiscal periods calculated.
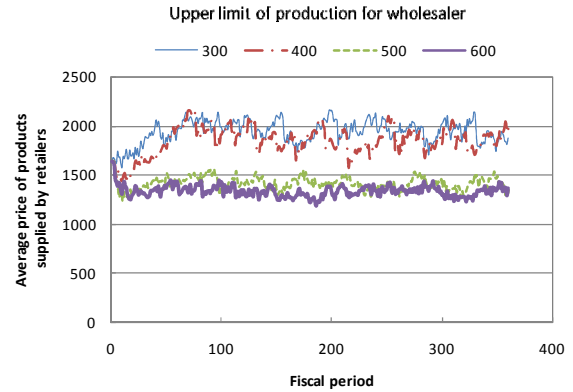

Figure 2 Change in the average price of products supplied by retailers for various levels of upper limit of production for wholesalers.

4.3 C-R-W-E-B simulation

When all agents are included in the system and both the investment rule of producers and transactions with the bank are taken into account, the total deposit money in the bank, total loaned money and total demand of consumers show cyclic change with fiscal period, representing a business cycle as shown in Figure 3. Here, total demand is defined as the total amount of money paid by consumers to buy products in every fiscal period. It was also observed that the total profit of producers shows large peaks during each booming stage.
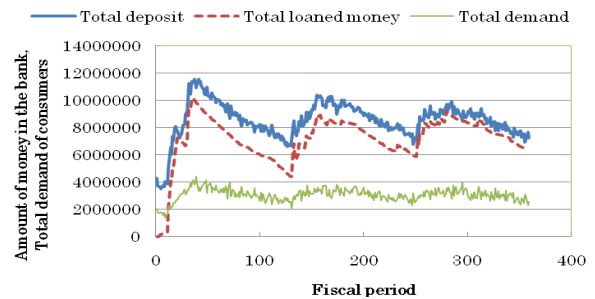

Figure 3 Cyclic change in total deposit, loaned money in the bank, and total demand of consumers, showing business cycle.

Figure 4 shows the total amount of wages paid to consumers. It is noted that the wages in equipment maker show a peak at the beginning of an economic recovery and the wages of other producers show the same cyclic change as those in Figure 3. This means that, at the beginning of each economic recovery, some of the producers invest in equipment to increase their production capacity. Consequently, the equipment maker gets a large profit, and then the wages of

consumers working in the equipment maker increase, resulting in an increase in the demand of various kinds of products of retailers. This in turn increases the wages for retailers as well as wholesalers and increases the demand of other kinds of products. Thus, a preferable circular movement for economic recovery occurs.
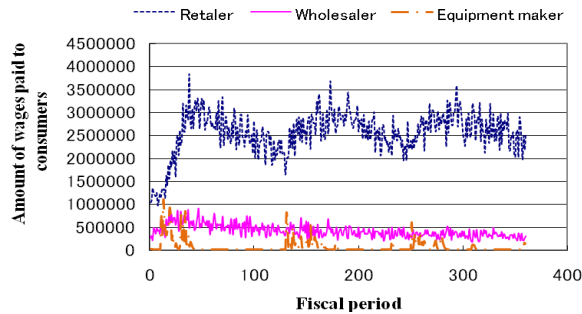

Figure 4 Cyclic change in the total amount of wages paid to consumers.

Average price of products supplied by retailers also shows a cyclic movement, but slightly decreases with fiscal period as shown in Figure 5. This is because the amount of products supplied by retailers gradually increases with fiscal period, due to an increase in the production capacity presented by investments. The total demand of consumers gradually increases with fiscal period because of the gradual decrease in price.
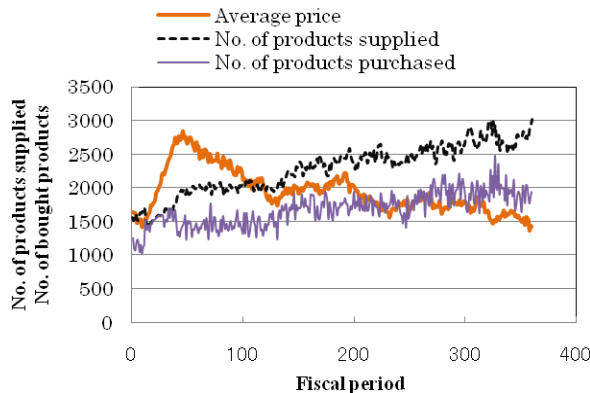

Figure 5 Cyclic change in the average price of products supplied by retailers and the number of products supplied and purchased.

When the bonus rule is not applied, namely the amount of wages is always constant even though producers obtained large profit, it was found that the business cycle does not occur and the total deposit of producers in the bank increases with increasing fiscal period as shown in Figure 6. It was also found that the number of products supplied decreases, the price of

products increases and 11 out of 20 retailers go into bankruptcy within 60 periods. This means that if the profit of producers is not partly distributed as the wages of consumers, the demand of consumers is not stimulated by the profit of producers, money of loser's moves toward winners and market becomes oligopolistic. This suggests that the profit of producers has to be distributed to consumers in order for the economy to properly recover.
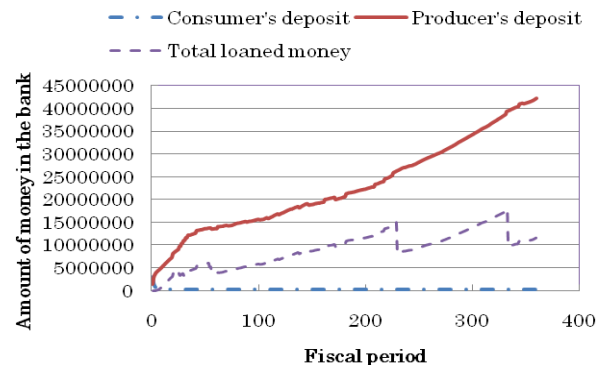

Figure 6 Total deposit and loaned money in the bank.

5. Conclusions

A multi-agent model for a fundamental economic system which involves self-adjusting mechanisms of price, production and investment has been developed. It was revealed that this artificial economic system shows realistic behavior of the market such as the price in equilibrium, business cycles with boom and recession stages, investment by producers, bankruptcy, etc.

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