

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

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*ABSTRACT.* An artificial economic system composed of producers, consumers, and a bank was modeled and macroscopic behavior of the system was simulated, assuming that consumers buy products within the limit of their disposable income, selecting the cheapest product on the market, while producers hire consumers, pay them salary, feed products to the market adjusting both the amount and price of the products based on the stock and total sales, and sometimes invest in equipment, borrowing money from a bank. As a result, it was revealed that characteristic behaviors of a real economic system such as equilibriums of market price, fund circulation among agents and business cycle etc. can be obtained as a result of the simulation based on the microscopic rules of the acts of each agent and the interaction among them.

**Keywords:** Multi-agent Simulation, Agent-based Modeling, Economic system, Fund Circulation, Business Cycles

### 1. Introduction

Multi-Agent Simulation has come into wide use in recent years in order to analyze the macroscopic behavior of social systems, based on microscopic rules of the acts of agents[1]. Since many social problems relate to an economical aspect, it seems important to construct a model for economic systems that can explain fundamental economic behavior, such as the equilibriums of price and the amount of goods on the market, gross national product, and business cycles, etc. Although economic systems are quite complicated, a multi-agent model could be a set of tools used to analyze the effects of economical policies or the behavior of economic systems from the viewpoint of first principles, namely the rules of the acts of agents and their interactions. However, not so many previous studies[2-8] tried to construct a model that can calculate macroeconomic variables based on microscopic rules of the acts of agents and their interactions, and more study seems necessary to elucidate the fundamental conditions for establishing a model that can be used for practical purposes.

N. Basu et al.[5], for example, presented a simulation model of the economy called Aspen, which involves a self adjusting mechanism of price and production. However, many of the details on the calculation conditions that would be optimum in simulating economic systems are still uncertain. For example, it is assumed in the Aspen[5-7], that the action

rules of consumers in buying goods are given in the form of probability function, and the amount of goods to be produced by a producer is given in the form of production function which is represented as a function of the number of machines in the factory and the number of employees. As an alternative rule, we can assume the action rules of simpler form without using mathematical functions, in which consumers select the cheapest goods on the market, and producers determine the amount of production based on the amount of goods in stock at the end of each period.

Endogenous business cycles would be another important aspect of economic behavior. Some literatures[7,8] report that a business-like cycle emerges as a result of calculation, but the details on the influential factors, such as the factors that affect the period of business cycles, etc., seem to be still uncertain.

This paper presents a multi-agent model for a fundamental economic system with realistic behavior that involves a self-adjusting mechanism of price, production, and investment, based on the rules of the acts of agents which are defined as simple as possible.

## **2. Simulation Model**

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

The microscopic rules of the actions of agents are defined as follows so that they are simple and essentially close to that of a real system.

Consumers are assigned to one of the producers for working, obtaining wages, and buying several kinds of products, according to their utility function within their disposable income, selecting the cheapest product on the market for each kind out there. Each consumer has a bank account, deposits a part of their wages, and withdraws money before purchasing at every fiscal period. Disposable income is defined as the wages plus withdrawn money from a 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 into 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 amount of goods in stock at the end of the previous period and the total sales during the last 10 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 demand at each fiscal 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 a certain kind of product when produced products all remain unsold for 20 periods. The producer goes

bankrupt when they halt 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 investment.

The bank keeps the surplus money of consumers and producers in 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 non-performing bond, and the 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. The total system, as a market, is also represented as an instance of a class that includes the above-mentioned objects.

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

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	60002-4000 at random	4000-8000 at random	4000-8000 at 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

First, is the C-R simulation, where consumers, represented as “C”, and retailers, represented as “R”, are assumed to be only agents in the system, and the equilibrium mechanism concerning price is simulated by changing the condition of determining the amount and price of products in production planning at every fiscal period. Here, the initial price of products is determined as triple the production cost that is given randomly, the upper limit of production is not set, and the disposable income of each consumer is assumed to be constant and assigned randomly. Investment and bankruptcy are neglected.

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

Third, is the C-R-W-E-B simulation, where equipment makers, represented as “E”, and a bank, represented as “B”, are included in the system. The investment actions of “R” and

“W” are taken into account. Here, producers deposit surplus money into the bank and borrow money as short-term loans when money at hand becomes short. Wages paid to employees are composed of a constant wage and a variable one, a bonus, and the latter is paid when surplus money for the producer exists after paying all expenses. The borrowed money for the investment is a long-term loan and constantly paid back in 120 fiscal periods.

## 4. Simulation Results

### 4.1. C-R Simulation

The calculated results of each average price and number of products supplied or purchased in the market are shown in Figure 1, as a function of the fiscal period where the determining rules of both the price and amount of each kind of product are applied. Here, it should be noticed that the total demand of consumers is constant because the disposal income of consumers is assumed to be constant. Under this assumption, as shown in Figure 1, the 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 number of products supplied or purchased tend to find equilibrium in the final stage of calculation. This result shows that the present model involves self-adjusting mechanisms of both price and the amount of production, although it takes more than 400 periods for equilibrium to be attained, the reason for which is that the demand of consumers is assumed to be constant.

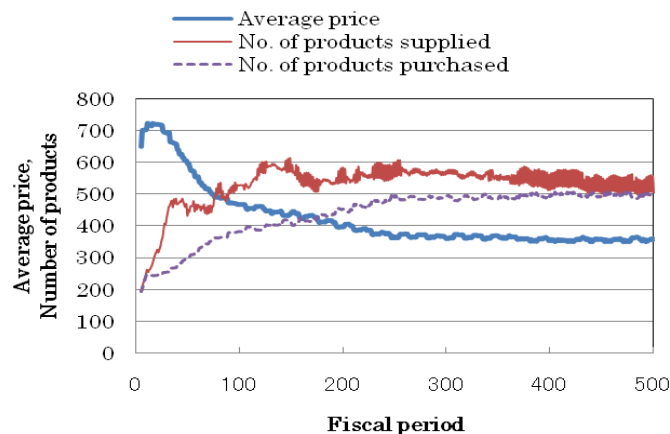


FIGURE 1. Changes in the average price of products in the market and the number of products supplied or purchased

### 4.2. C-R-W Simulation

When wholesalers are included in the system, retailers buy raw materials supplied by wholesalers. The disposal income of the consumer is assumed to come from the wages paid by the producer, and 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 retailer demand.

The calculated average price of the products of retailers is presented in Figure 2. It is noted that the average price comes into 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. Furthermore, it is also noted in Figure 2 that the equilibrium value of the price is greater when the upper limit of the production of wholesalers is as small as 300 or 400. This is

because the numbers of the products of retailers supplied depends on the upper limit of the 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.

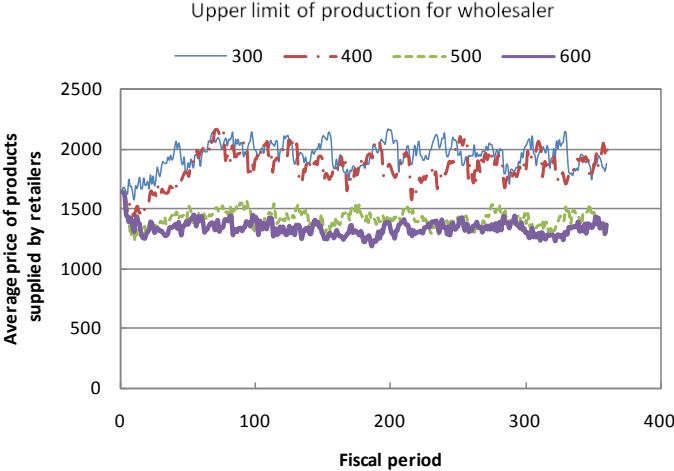


FIGURE 2. Changes in the average price of products supplied by retailers for various levels of the upper limit of production for wholesalers

**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 deposited money in the bank, total loaned money, and total demand of consumers show cyclic change with each 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 for purchasing products in every fiscal period.

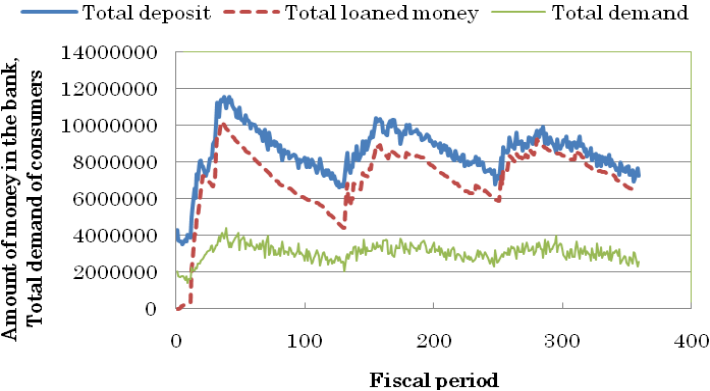


FIGURE 3. Cyclic changes in total deposits, loaned money in the bank, and the total demand of consumers, showing a business cycle, where repayment period is 120

It was also observed that the total profit of producers and the number of investments conducted by the producers show large peaks during each booming stage. In addition, it is noted that the period between the peak and the valley of the business cycle shown in Figure 3 is almost 120, which is coincident with the repayment period for a long-term loan.

Figure 4 shows the total amount of wages paid to consumers. It is noted that the wages from an 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. The intermittent increase in the wages of employees working at the equipment maker during the first stage of economic recovery is due to the occurrence of investments conducted by the retailers and wholesalers, whose amount of production reaches the upper limit of production capacity.

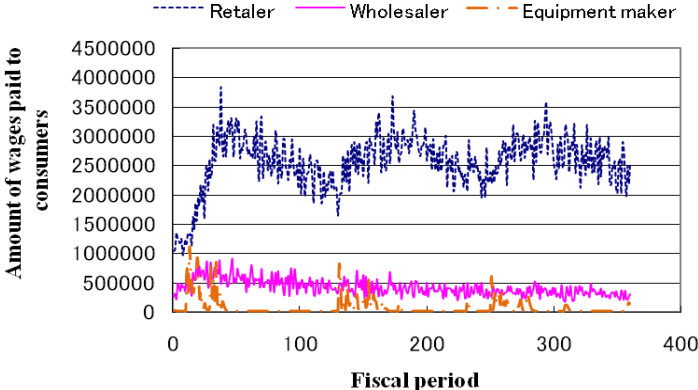


FIGURE 4. Cyclic changes in the total amount of wages paid to consumers

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

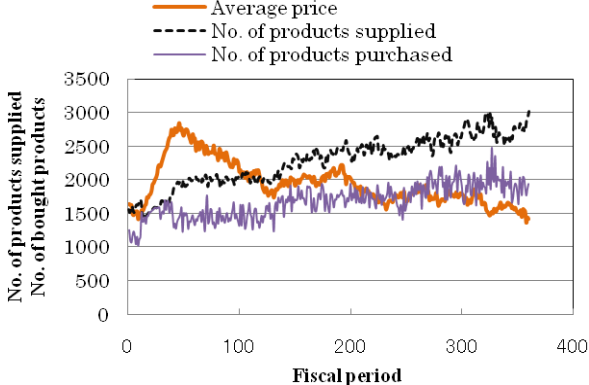


FIGURE 5. Cyclic changes in the average price of products supplied by retailers and the number of products supplied and purchased

From these results, the mechanism of the business cycle shown in Figure 3 is considered as follows. At the beginning of the booming stage, some of the producers whose production costs are lower than others increase their production amount to meet the demand within the limit of their production capacity. Then, they decide to invest in equipment to increase their production capacity, resulting in a larger profit for the equipment maker. This,

in turn, results in the increase of employee wages working at the equipment maker, because a part of the profit of the producer is paid to its employee every fiscal year based on the bonus rule. As a result, the demand of various kinds of retailer products increases due to the increase in the purchasing power of employees at the equipment maker. This, in turn, increases the profit and wages for retailers, as well as wholesalers, and increases the demand for other kinds of products. Thus, a preferable circulation for economic recovery occurs. On the other hand, since the price of products increases and the frequency of investment conducted by producers decreases during the booming stage, the price level tends to decrease at some stage because of the decrease in the demand and the halting of investment by producers. Thus, the business cycle turns to a recession stage. After that, another booming stage begins due to decreases in the price levels.

According to the mechanism stated above, the business cycle shown in Figure 3 is closely related to investment. In other words, the economic recovery essentially occurs due to the fact that the producer, who intends to invest in equipment, borrows money from the bank, and the borrowed money is paid to the equipment maker, resulting in the increase in the wage level of consumers, which, in turn, increases the demand for goods in the market.

In order to confirm the above-mentioned mechanism, additional calculations were conducted where the repayment period was changed to 60 or 180. It was confirmed that a calculated business cycle is always coincident with the repayment period employed in the calculation. An example for the repayment period of 60 is shown in Figure 6, where the period of business cycles coincides with 60, the repayment period. This means that the essential reason for the business cycle in the present study is the cyclic change in the fluidity of funds in the market.

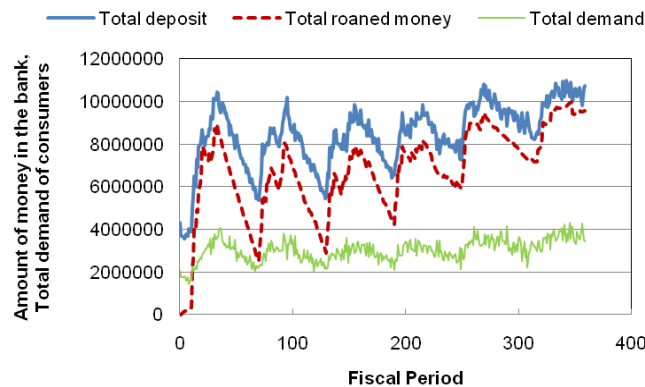


FIGURE 6. Cyclic changes in total deposits, loaned money in the bank, and the total demand of consumers, where the repayment period is 60

When the bonus rule is not applied, namely, when the amount of wages is always constant even though producers obtained large profits, it was found that the business cycle comes to a stop and the total deposits of producers in the bank increases with each fiscal period, as shown in Figure 7. 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 lost by one moves toward the winner, and the market becomes oligopolistic. This suggests that the profit of producers has to be distributed to consumers in order for the

economy to properly recover.

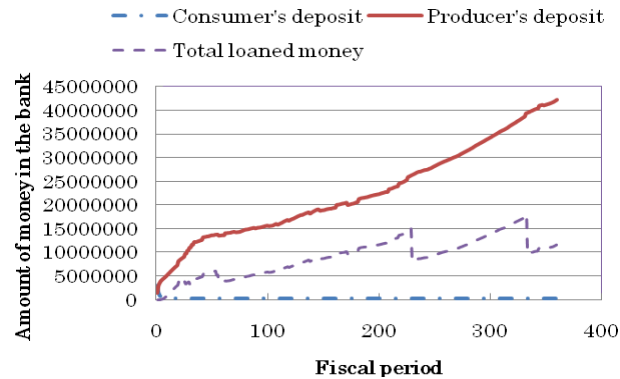


FIGURE 7. Total deposits and loaned money in the bank when the bonus rule is not applied.

## 5. Conclusions

A multi-agent model for a fundamental economic system that involves self-adjusting mechanisms of price, production, and investment has been developed. It was revealed that this artificial economic system shows the realistic behavior of the market, such as the price in equilibrium and business cycles with boom and recession stages, etc., and the period of the calculated business cycle is coincident with the repayment period of long-term loans, which are fixed in the present calculation. This suggests that the essential reason for the endogenous business cycle is the cyclic change in the fluidity of funds in the market.

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