

Analysis of Business Cycle and Fund Circulation in Multi-Agent Simulation of an Artificial Economic System Composed of Consumers, Producers and a Bank

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Abstract. A multi-agent model for a fundamental economic system composed of producers, consumers and a bank, which involves self-adjusting mechanisms of price, production and investment, has been developed. The effects of influential factors on business cycle and GDP have been analyzed and following results have been obtained. The period and pattern of business cycle are strongly related to the repayment period and its variance. Calculated GDP is mainly dependent on the money required for investment and total money of consumers for buying. These results suggest that business cycle occurs due to the repetition of flowing out and in of funds between the bank and market accompanied by the increase or decrease in the loan of producers and income of consumers, caused by the investment and repayment by producers.

Keywords: multi-agent simulation, agent-based modeling, artificial economic system, business cycle, fund circulation, gross domestic product, GDP, input-output table

1 Introduction

Multi-Agent Simulation has been widely used in recent years to analyze the macroscopic behavior of social systems based on microscopic rules of acts of agents and interactions among them. Previous research works [1-4] in this field have dealt with various problems in social systems such as epidemic disease, community problem, 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. There are, however, not many cases reported so far in the previous works, which simulate fundamental behaviors of economic systems such as a self-adjusting mechanism of price and production in the market, fund circulation, business cycles with boom and recession, etc.

Some of the present authors have presented[5] a multi-agent simulation of fund circulation in an artificial economic system which involves self-adjusting mechanism of price, production and investment. They revealed that the calculated macroscopic

behavior of the artificial economic system recreates characteristic behavior of a real system in that the market price tends to an equilibrium price and a business cycle emerges through the fund circulation among agents, etc. The basic mechanism of emerging business cycle are also discussed in this study[5], the details of which, however, remain to be clarified further. This paper presents an analysis of business cycles, GDP and fund circulation in order to clarify the conditions and mechanism of business cycles and influential factors on GDP in this artificial economic system.

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. Other important sets in the model are product in the market and product class which is a class of products produced by producers. Macroscopic characteristics of economic systems such as market price of products, fund circulation, GDP etc. are considered to be generated as a result of the interactions among agents.

The microscopic rules of acts 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 within the limits of cash at hand, and select the cheapest product in the market for each type of product. Each consumer has a bank account, deposits a part of wages according to the savings ratio and withdraws money according to the withdrawal ratio before the purchasing action at every fiscal period. The wages are composed of a fixed salary which is assigned to each consumer randomly between lower and upper limits and a bonus which is given when surplus money exists in the bank account of corresponding producer after paying the fixed salary. The amount of bonus is defined as the bonus ratio times of the producer's deposit.

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 products, where the amount of production is decided based on both the amount of goods in stock at the end of 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. 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.

In addition, retailers and wholesalers invest in equipment to increase their production capacity by buying equipment from the equipment maker. For the decision

making for investment, each producer has a flag number for investment which is added by one when his products are all sold out under the production of upper limit in capacity. The decision for investment is made when the flag number reaches a critical number. The critical number is set to be 10 in the present study, and the production capacity is assumed to be increased by 50% after the investment.

The bank keeps surplus money of other agents in their bank accounts, and lends money to producers according to their demands for investment with the interest rate of 1%. Here, it is assumed that initial amount of money possessed by the bank is so large that the bank can afford to lend any amount of money to meet the requirement of producers for investment. The lent money is paid back constantly by the producers in the repayment period defined between 60 to 180 fiscal periods. On 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. Amount of cash and deposit of each agent at the beginning of each fiscal period are represented according to the present model as given in Equation (1).

$$\begin{aligned}
 C_{kc}^i &= C_{kc}^{i-1} + D_{kc}^{i-1} r_{withdraw_{kc}} - Buy_{kc}^{i-1} + (Const_wage_{kc}^{i-1} + Bonus_{kc}^{i-1})(1 - r_{saving_{kc}}) \\
 D_{kc}^i &= D_{kc}^{i-1} (1 - r_{withdraw_{kc}}) + (Const_wage_{kc}^{i-1} + Bonus_{kc}^{i-1}) r_{saving_{kc}} + Interest_{kc}^{i-1} \\
 D_{kp}^i &= D_{kp}^{i-1} + Sales_{kp}^{i-1} - (Cost_{kp}^{i-1} + \sum_{k \in \{kc\}} (Const_wage_k^{i-1} + Bonus_k^{i-1}) + Re\ payment^{i-1} - Interest^{i-1})
 \end{aligned} \tag{1}$$

where, kc : suffix for consumers, kp : suffix for retailers

C^i : Cash possessed by agent at the beginning of i^{th} fiscal period

D^i : Deposit of agent in the bank at the beginning of i^{th} fiscal period

Buy^i : Expenditure of consumer to buy retail products during i^{th} fiscal period

$Cost^i$: Expenditure of retailer to buy raw materials from wholesalers during i^{th} fiscal period

$Const_wage^i$: Constant wage of consumer paid by retailer or wholesaler at i^{th} fiscal period

$Bonus^i$: Additional wage of consumer paid by retailer or wholesaler at i^{th} fiscal period

$Interest^i$: Balance of interest paid by the bank

$Repayment^i$: Decrease agent in the balance of loaned money at i^{th} fiscal period

$r_{withdraw}$: Ratio of withdrawal money to total deposit

r_{saving} : Ratio of savings to total cash at the end of every fiscal period

□ $Sales$: Total sales obtained by selling products at i^{th} fiscal period

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.

In order to elucidate the behavior of fund circulation and the influence of various factors on business cycle and GDP, four types of analysis are conducted. Fund

circulation is represented in the form of input-output table of circular flow of funds for a typical calculation condition. The simulation conditions are given in Table 1.

As a basic condition, initial flag number for investment, repayment period in investment and savings ratio are set to be 0,120 and 0.1 respectively, while bonus ratio and withdrawal ratio are set to be, 0.8-0.9 and 0-1 respectively using uniform random numbers.

In the analysis of investment condition, the initial condition of flag number and the repayment period are changed in order to elucidate overall behavior of fund circulation and the mechanism of the formation of business cycles in this artificial economic system. Here, repayment periods are set to be constants or uniform random numbers between 60 and 180 or normally distributed random numbers with average value of 120 and various variance values.

In other three types of analysis, number of agents, amounts of required money for unit investment and amount of initial funds are changed as shown in Table 1, and the influences of these factors on GDP are analyzed.

In addition, influences of savings ratio, withdrawal ratio and bonus ratio on GDP are analyzed, where bonus ratio and withdrawal ratio are set to be 0-0.9 and 0-1 respectively using uniform random numbers under the savings ratio of 0.1 or 0.5.

Table 1. Simulation conditions.

Condition	Basic condition	Analysis of investment			Analysis of agent number	Analysis of amount of unit investment	Analysis of total amount of initial funds
					Analysis I	Analysis II	Analysis III
Trun time	360						360
Number of agent	C Agent	100	100	100/200/300/400/500		100	
	R Agent	20	20	20/40/60/80/100		20	
	W Agent	3	3	3/6/9/12/15		3	
	E Agent	1					1
	B Agent	1					1
Initial investment flag	0	0/0~10 in Random				0	
Amount of unit investment	1000000	1000k			400k /600k /2000k	1000k	
Repayment period	120	60/120/180 (Constant)	60~180 in random	Normd distribution Average:120 Variance:0/300/1200	120 (Constant)		
Bonus ratio	0.8~0.9 in random	0.8~0.9 in random					
Savings ratio	0.1	0.1					
Withdrawal ratio	0~1 in random	0~1 in random					
Initial funds of C	30k~50k in random	30k~50k in random				2~5 times of basic condition	
Initial funds of R & W	80k~160k in random	80k~160k in random				2~5 times of basic condition	

Number in random stands for uniform random number.

4 Simulation result

4.1 Fundamental behavior of fund circulation in the artificial economic system

When the basic conditions in Table 1 is applied, where the repayment period is set to be constant, the total deposit and loaned money in the bank and total demand of consumers show cyclic change with fiscal period, showing a business cycle, as represented in Figure 1. Here, total demand of consumers is defined as the total amount of money paid for buying products by consumers in every fiscal period. This

is the result of fund circulation in this artificial economic system. An example of the calculated input output table, representing circular flow of funds, is shown in Table 2.

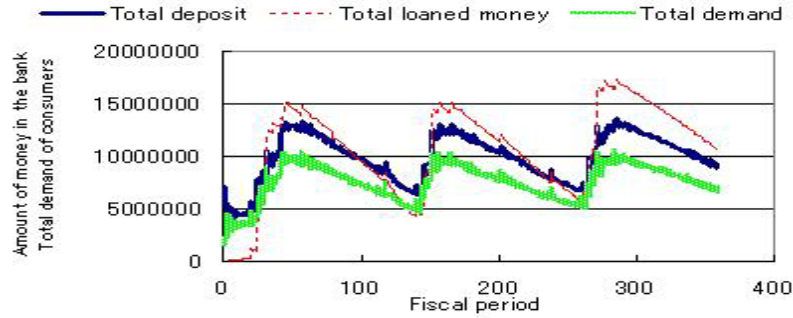


Fig. 1. Cyclic change in total deposit and loaned money in the bank, and total demand of consumers, showing business cycle.

Table 2. An example of input-output table showing circular flow of funds in the system.

	Retailer	Wholesaler	Equipment maker	Bank	Total of intermediate sectors	Consumption expenditure	Gross domestic fixed capital formation	Increase in stocks	Total domestic final demand	Total domestic demand
Retailer	-	-	-	-	0	4439751	-	-14415	4425336	4425336
Wholesaler	150442	-	-	-	150442	-	-	-450	-450	149993
Equipment maker	-	-	-	-	0	-	1000000	-	1000000	1000000
Bank	14242	-60	-555	-	13627	-356	-	-	-356	13272
Total of intermediate sectors	164684	-60	-555	-	164070	4439395	1000000	-14864	5424531	5588600
Compensation of employees	3949752	147816	978142	6478	5082987					
Operating surplus	262726	2436	21412	6795	293369					
Depreciation of fixed capital	48174	0	-	-	48174					
Total of gross value	4260652	150052	1000554	13273	5424531					
Domestic production	4425336	149993	999999	13273	5588600					

Other features in the calculated business cycle are that the amount of wages paid to consumers and average price of products shows similar cyclic movement with fiscal period. It is also noted that the period of business cycles is coincident with the repayment period when the repayment periods of all producers are assumed to be same. From these results, the mechanism of occurring business cycle in this artificial economic system is considered as follows. In 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, resulting in the increase in the wages of consumers working at the equipment maker, followed by 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. During the economic recovery stage, average price of products gradually increases, resulting in the decrease of total demand of consumers and the requirement of new investment hardly takes place. Thus, a booming economy turns into an economy with recession at some point in time.

4.2 Influence of initial condition of investment flag

In the above calculation, initial flag number is set to be zero and repayment period is set to be constant. Under the condition where initial flag number is changed, it was found that the influence of the condition in initial flag number on business cycle or GDP is negligibly small. This is because the time period required for decision making for investment is far too small compared to the repayment period in the present study. This result seems to be reasonable because a similar condition in the time period for decision making and repayment would be valid in the actual system. From these results, it is concluded that the business cycle shown in Figure 1 is caused due to the investment by the producers for increasing their production capacity. In other words, the important aspect in the mechanism of occurring business cycle is that the money circulating in the system increases at the time of investment as the money borrowed by producers is paid to the equipment maker, which in turn is paid to consumers as wages, increasing the market demand.

4.3 Influence of the variance in repayment period

In the actual system, repayment periods of producers are not constant, but generally vary between short term and long term, depending on the producers' requirement. In order to simulate fund circulation when repayment periods are different for each producer, the variance of repayment period is changed with the expected value of repayment period being kept constant and its influence on the patterns of business cycle are analyzed. The analyzed result is shown in Figure 2.

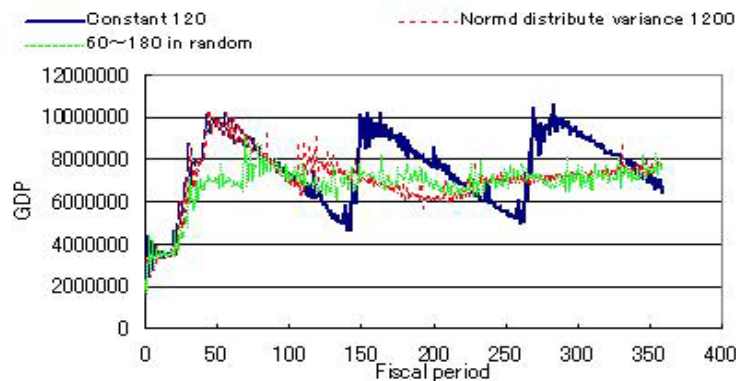


Fig. 2. Influence of variance in repayment period on business cycle observed in GDP.

It is noted as shown in Figure 2, that business cycle becomes indistinct when the variance in repayment period increases. When the repayment periods are set to be uniformly distributed random numbers between 60 and 180 as an extreme case, the tendency of cyclic up and down movement in GDP almost disappear as shown in Figure 2.

4.4 Influence of other factors affecting fund circulation on GDP

As the other factors such as the number of agents, amount of unit investment, savings ratio, etc. given in the analysis I, II, III in table 1 are also considered to affect fund circulation, their influence on GDP has been analyzed and following results have been obtained. When the numbers of all kinds of agents are equally increased, GDP proportionally increases with increasing the number of agents, while GDP per capita of consumers are almost constant. When the number of consumers is increased with the number of producers being kept constant, GDP increases but GDP per capita of consumer decreases, with an increase in the number of consumers. On the other hand, when the number of producers is increased with the number of consumers being kept constant, GDP per capita of consumer, increases with increasing the number of producers. It was also observed that GDP and GDP per capita of consumers also increases with increasing the initial funds of agents as well as increasing the amount of money required for unit investment. In addition, it was confirmed that GDP increases with increasing bonus ratio and withdrawal ratio, while GDP decreases with increasing savings ratio. The above-mentioned result implies that GDP essentially increases with increasing two factors, the factor which increases total amount of money required for investment such as the number of producers and amount of money for unit investment, and the factor which increases total demand of consumers such as initial funds of consumers, bonus ratio and withdrawal ratio. In order to confirm this inference, a linear multiple regression analysis was conducted. Here, two factors, total money of cash possessed by consumers just before buying action at every fiscal period averaged during first booming stage and total amount of loaned money borrowed by producers during first booming stage are evaluated for each calculation run and these factors are taken as explanatory variables and GDP as dependent variable. Obtained equation of multiple regression is given in Equation (2). As a result of the analysis of variance, it was concluded that the coefficient of multiple determination is 0.96 and multiple regression model shown in Equation (2) is applicable with the risk of 0.5% or less. The relationship between calculated GDP and estimated GDP by regression equation is shown in Figure 3.

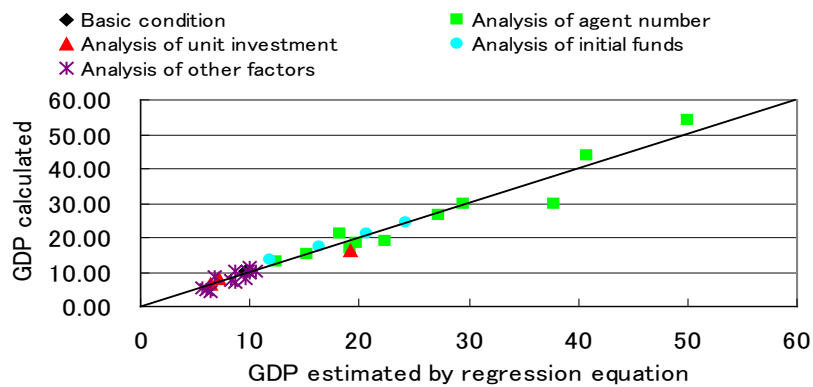


Fig. 3. Relationship between calculated and estimated GDP according to regression model.

$$y = -0.191 + 0.142x_1 + 0.695x_2 \quad (2)$$

where, y : maximum GDP during booming stage ($\times 10^6$)

x_1 : total money spent for investment during booming stage ($\times 10^6$)

x_2 : total cash of consumers averaged during booming stage ($\times 10^6$)

It would be noteworthy that total money lent from the bank is spent for investment and become someone's sales or income. Thus, it would be reasonable to conclude that GDP would increase with increasing total amount of cash available to be spent for buying something and total amount of funds spent for investment.

Conclusions

A multi-agent model for a fundamental economic system composed of producers, consumers and a bank, which involves self-adjusting mechanisms of price, production and investment, has been developed. The effects of influential factors on business cycle and GDP have been analyzed and following results have been obtained. The period of business cycle is coincident with expected value of repayment period. Business cycle becomes indistinct when the variance of repayment periods becomes large. Calculated GDP is represented as a function of two factors, total amount of money required for investment and amount of available money of consumers for buying. These results suggest that business cycle is considered to occur as a result of the repetition of flowing out and in of funds between the bank and market accompanied by the increase or decrease in the loan of producers and disposable income of consumers, caused by the investment by producers

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